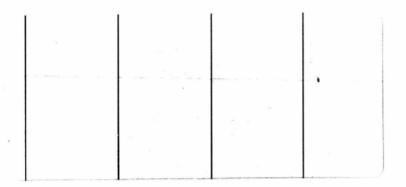
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# ATL TR 215 AN IMPROVED NUMERICAL PROCEDURE FOR THE PARAMETRIC OPTIMIZATION OF THREE DIMENSIONAL SCRAMJET NOZZLES

Ву

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## TR 215 SECTION 1 INTRODUCTION

This report describes a parametric numerical procedure permitting the rapid determination of the performance of a class of scramjet nozzle configurations. The geometric complexity of these configurations rules out attempts to employ conventional nozzle design procedures, Reference (1), wherein properties at the nozzle exit plane are specified and wave cancellation techniques are then employed to design the wall surfaces. It is not feasible to stipulate exit conditions a priori and wave cancellation techniques employing three dimensional characteristics are beyond the current state of the art.

The current approach is an extension of work discussed in Reference (2) and employs a characteristic grid network with Riemann invariants as variables. Lateral expansion effects are incorporated via one dimensional approximations as suggested in Reference (3).

The numerical program developed permits the parametric variation of cowl length, turning angles on the cowl and vehicle undersurface and lateral expansion and is subject to fixed constraints such as the vehicle length and nozzle exit height. The program requires uniform initial conditions at the burner exit station and yields the location of all predominant wave zones, accounting for lateral expansion effects. In addition, the program yields the detailed pressure distribution on the cowl, vehicle undersurface and fences, if any, and calculates the nozzle thrust, lift and pitching moments. Viscous effects are included in the latter via the Spalding-Chi method described in Reference (4). Local heat transfer coefficients are computed from a modified Reynolds' analogy. Local vehicle external flow interaction and/or plume boundary effects are computed insofar as they affect vehicle under surface pressure distributions.

Due to the differing techniques required for the calculation of ideal gas flows as compared to equilibrium flows, two separate numerical programs have been developed. The first program analyzes constant  $\gamma$  ideal gas flow fields and a listing of this program is provided in Appendix II. The second

program analyzes equilibrium hydrogen-air flow fields via equilibrium curve fits and its listing is provided in Appendix III. A complete program description is provided in Appendix I.

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#### SECTION 11

#### NUMERICAL PROCEDURES

Consider a typical nozzle configuration as depicted in Figure (1), where the lateral expansion distribution Z(x) may result from a combination of several nozzles merging into a single nozzle. It is assumed in this pre-liminary analysis that the jets after merging are bounded by sidewalls which extend downstream of the merged section. The initial flow (at the burner exit) is represented as an average uniform flow. The assessment of nonuniformities at the entrance station may be obtained applying the numerical procedure described in Reference (5).

A. Ideal Gas Grid Point Calculation - Consider the calculational procedure required to determine the location and properties of a point 3 (as shown in Figure 2) where properties at 1 and 2 are known and 1-3 and 2-3 are characteristic surfaces. Along these surfaces the Riemann invariants are defined as

$$C_{\pm} = v + \theta \tag{1}$$

where  $\nu$  is the Prandtl-Meyer function and  $\theta$  the local flow deflections. Then at point 3

$$v_3 = \frac{1}{2} (v_1 + v_2) + \frac{1}{2} (\theta_1 - \theta_2)$$
 (2a)

$$\theta_3 = \frac{1}{2} (v_1 - v_2) + \frac{1}{2} (\theta_1 + \theta_2)$$
 (2b)

Employing the two dimensional value of expansion  $\Delta v_3$  (from initial condition i) the Mach number M<sub>3</sub> is obtained via the Prandtl-Meyer relation (where i denotes uniform initial flow properties at the burner exit)

I

$$\Delta v_{3} = v_{3} - v_{1} = \sqrt{\frac{\gamma+1}{\gamma-1}} \left( \tan^{-1} \sqrt{\frac{\gamma-1}{\gamma+1}} \right) \left( \frac{M_{3}^{2}-1}{M_{3}^{2}-1} - \tan^{-1} \sqrt{\frac{\gamma-1}{\gamma+1}} \right) \left( \frac{M_{1}^{2}-1}{M_{1}^{2}-1} \right)$$

$$- \left( \tan^{-1} \sqrt{M_{3}^{2}-1} - \tan^{-1} \sqrt{M_{1}^{2}-1} \right)$$
(3)

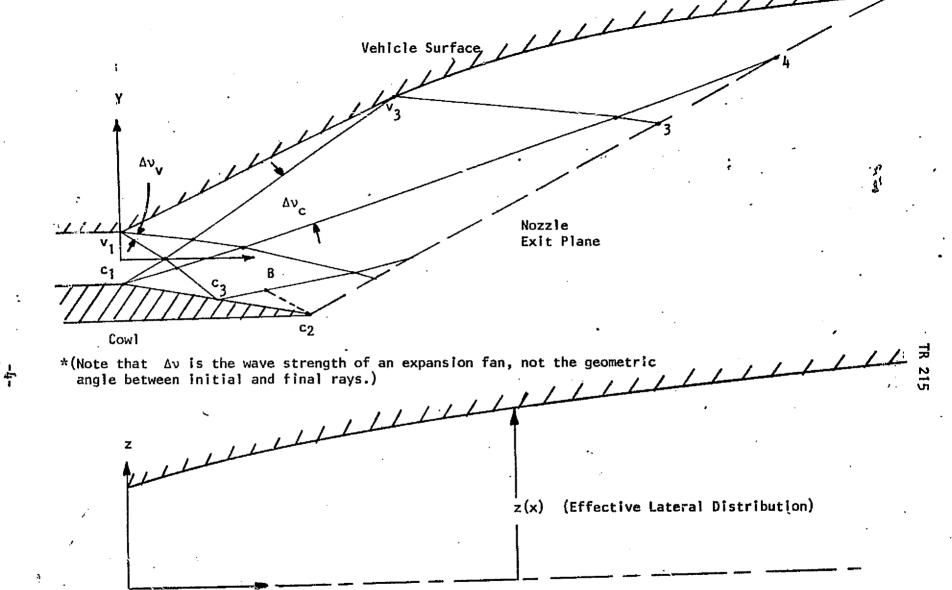
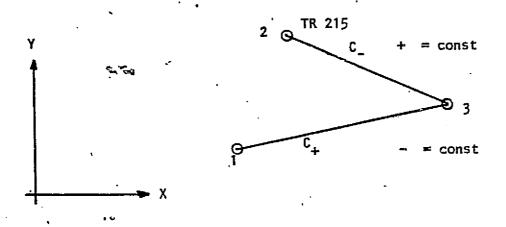
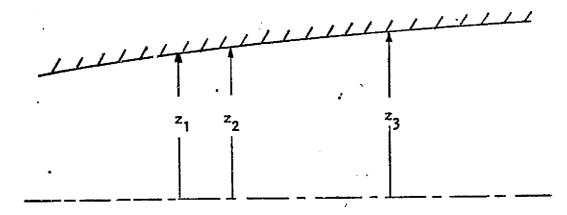


FIGURE 1. TYPICAL NOZZLE CONFIGURATION

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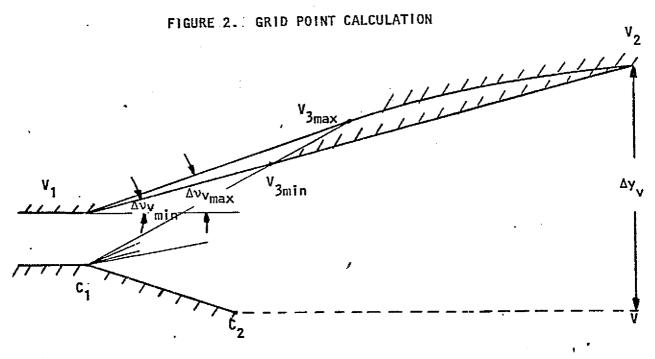


FIGURE 3. VARIATION OF VEHICLE EXPANSION WAVE STRENGTH

employing an iterative procedure to solve this transcendental equation for  $M_2$ . Then, with the Mach angle determined

$$\mu_3 = \sin^{-1} \left(\frac{1}{M_3}\right)$$
 (4)

Equations (7a) and (7b) yield a tentative location for point 3, and the area ratio  $(A/A^*)_3$  is calculated based on two dimensional considerations.

$$\frac{(\frac{A}{A_{+}})_{3}}{(\frac{\gamma+1}{2})_{3}} = \frac{\frac{M_{3}}{3} \frac{(1+\frac{\gamma-1}{2}M_{3}^{2})}{\frac{\gamma+1}{2(\gamma-1)}}}{(\frac{\gamma+1}{2})_{3}}$$
 (5)

This ratio is corrected for lateral expansion by multiplying it by the ratio  $Z_3/Z_1$  where the lateral expansion variable is expressed by a suitable polynomial curve fit

$$Z(x) = Ax^2 + Bx + C (6)$$

where  $Z_3 = Z(x_3)$  and  $Z_i$  denotes the lateral extent of the nozzle at the initial station. The location  $(x,y)_3$  is determined from

$$\frac{y_3^{-\gamma}_{1,2}}{x_3^{-x}_{1,2}} = \frac{1}{2} \left[ \tan(\theta_{1,2} \pm \mu_{1,2}) + \tan(\theta_3 \pm \mu_3) \right]$$
 (7a,b)

then

$$(\frac{A}{A_{+}})_{3} = (\frac{A}{A_{+}})_{3} * z_{3}/z_{1}$$
 (8)

The three dimensional corrected Mach number is obtained by replacing the two dimensional area ratio in Equation (5) by the three dimensional value given by Equation (8), and solving Equation (5) for  $M3_{30}$  by an iterative process.

Equations (7a) and (7b) are resolved using the corrected Mach angle  $\mu_{3D}$  and the entire procedure is repeated until two successive values of  $x_3$  agree to within a prescribed tolerance.

A similar procedure is used to determine properties at grid points on boundaries with Equation (7a) or (7b) replaced with an equation describing the body geometry. Desired variables (P, T etc.) are then simply obtained by isentropic, constant γ expansions from initial conditions.

B. Equilibrium Flow Grid Point Calculation - The geometric location of point 3 is obtained employing Equations (7a) and (7b) and properties  $(\nu,\theta)_3$  are obtained using Equations (2a,b) just as for the frozen calculation. The known two dimensional value of expansion  $\Delta\nu_3 = \nu_3 - \nu_2$  is subdivided into a series of small  $\Delta\nu_3$  increments. The initial value of isentropic exponent is obtained from

$$\Gamma = \Gamma (P, \phi, h) \tag{9}$$

where Equation (9) has been curve fit for equilibrium hydrogen-air as described in Reference (5).

The characteristic compatibility relation

$$\frac{d \ln P}{\Gamma} + \frac{d \nu}{\sin \mu \cos \mu} = 0 \tag{10}$$

applied across the interval  $\Delta v_j$  yields the pressure, holding  $\mu$  and  $\Gamma$  equal to their value at the start of the increment. The density is obtained from the isentropic pressure-density relation

$$P/p^{\Gamma} = constant$$
 (11)

The velocity is obtained from the Bernoulli relation;

$$\frac{dP}{\rho} + \frac{1}{2} dV^2 = 0 {12}$$

the enthalpy from the constancy of stagnation enthalpy;

$$h + \frac{1}{2} V^2 = H = constant$$
 (13)

and the Mach number from;

. 
$$M = V/a; a = \left(\frac{\Gamma P}{\rho}\right)^{\frac{1}{2}}$$
 (14)

where  $\Gamma$  has been reevaluated employing Equation (9). This procedure is repeated in small steps  $\Delta v_j$  until the full wave  $\Delta v_3$  has been integrated. Having the two dimensional value of  $M_3$ , point 3 can be tentatively located employing Equations (7a) and (7b). Then, the two dimensional area ratio can be computed from mass flow considerations

$$(A_3/A_1)_{20} = \rho_1 V_1/\rho_3 V_3 \tag{15}$$

Since the effective area based on three dimensional considerations is

$$(A_3/A_1)_{3D} = (A_3/A_1)_{2D} * Z_3/Z_1$$
 (16)

the product  $\rho_3$   $V_3$  must be divided by  $Z_3/Z_1$  to conserve mass flow

$$(\rho_3 V_3)_{3D} = (\rho_3 V_3)_{2D} * \frac{Z_1}{Z_3}$$
 (17)

Then an iteration procedure is performed to determine the value of three dimensional expansion  $(\Delta v_3)$  The correct value being that which yields  $(\rho_3 v_3)_{30}$  after application of the integration procedure of Equations (9) thru (14), and an update of the location of point 3 using Equations (7a) and (7b)

#### TR 215

#### SECTION 111

#### DETERMINATION OF NOZZLE FLOW FIELDS

A nozzle calculation is performed subject to the following constraints:

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- 1. The initial profile is uniform. For the frozen flow (constant  $\gamma$ ) calculation this requires specification of the pressure  $p_i$ , flow deflection angle  $\theta_i$ , Mach number  $M_i$ , and specific heat ratio  $\gamma$ . Fo the equilibrium calculation one must specify  $P_i$ ,  $\theta_i$ ,  $M_i$ , the temperature  $T_i$  and the fuel-air equivalence ratio  $\Phi_i$ .
- 2. The initial turning at the vehicle undersurface  $(\Delta v_V)$  and cowl  $(\Delta v_C)$  occur via sharp corners as depicted in Figure (1).
- 3. The wall segments downstream of these sharp corners remain straight until the expansion waves emanating from the cowl and vehicle undersurface reach the walls (points  $V_3$  and  $C_3$  of Figure 1).
- 4. The nozzle exit height is specified  $(y_{v_2} y_{c_2})$ .
- The recompression on the vehicle undersurface (between  $V_3$  and  $V_2$ ) is parabolic while the cowl between is straight, (i.e., constant slope from  $C_1$  to  $C_3$ ).
- The lateral expansion Z(x) is specified via a geometric curve fit.
- 7. The cowl length and vehicle length are specified.
- 8. Local cowl external flow properties are specified.

The numerical logic employed in the parametric design procedure is to treat the cowl length  $(x_{C_2}-x_{C_1})$  and the vehicle undersurface expansion  $\Delta v_{\nu}$  as

parametric variables for fixed values of cowl turning  $\Delta v_c$ , nozzle exit height, lateral expansion and vehicle length. Initially, a short cowl length should be chosen such that the expansion waves from the vehicle expansion fan miss the cowl. For this cowl length, the value of the vehicle undersurface expansion wave is varied in small increments, the minimum amount of turning being that which introduces no recompression in the region  $V_3$  to  $V_2$  (i.e., the undersurface has no curvature) to a value for which the recompression produces zero deflection at the end of the vehicle. This is illustrated in Figure (3). Then the cowl length is increased in specified increments and the entire procedure is repeated.

For a given nozzle configuration, the calculational procedure is as follows: Point  $V_2$  is located and vehicle expansion  $(\Delta v_V)_{\min}$  is determined and semented into small increments  $(\Delta v_i)_V$ . The cowl expansion array is swept out by segmenting  $\Delta v_C$  into small segments  $(\Delta v_i)_C$  and the interaction of each ray with the vehicle expansion is determined upto the vehicle surface (or exit plane) as discussed in Section II.

After completing the cowl expansion, it must be determined whether the first ray from the vehicle expansion intersects the cowl surface. If not, priperties at  ${\bf C_2}$  are determined by inserting a data point B (Figure 4) on the final cowl ray such that the characteristic  ${\bf BC_2}$  intersects point  ${\bf C_2}$ . The reflected ray at  ${\bf C_2}$  is computed upto the vehicle surface or until the exit plane is crossed. If the first vehicle ray does intersect the cowl before  ${\bf C_2}$  the intersection is determined and the reflected ray computed up to the vehicle undersurface or upto the exit plane. The calculation proceeds to the next vehicle expansion ray and the above repeated until Point  ${\bf C_2}$  is reached. Note if the vehicle surface is chosen sufficiently long all cowl rays may be "captured" on the vehicle. In this case the local external flow and/or plume shape may affect the vehicle undersurface pressure distribution. The program automatically determines if such a calculation is to be performed. Figures (4) through (9) illustrate typical exit conditions.

Upon completion of the minimum vehicle turning configuration, the vehicle expansion is incremented by a specified amount and the above process repeated

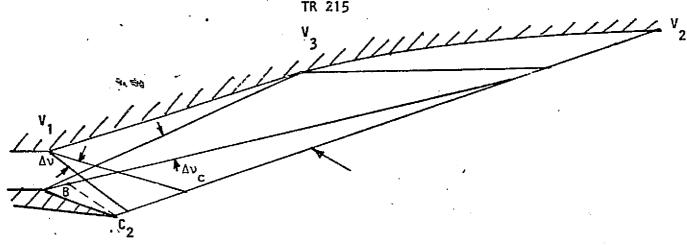


FIGURE 4. PARTIAL REFLECTION OF COWL EXPANSION/
NO REFLECTION OF VEHICLE EXPANSION

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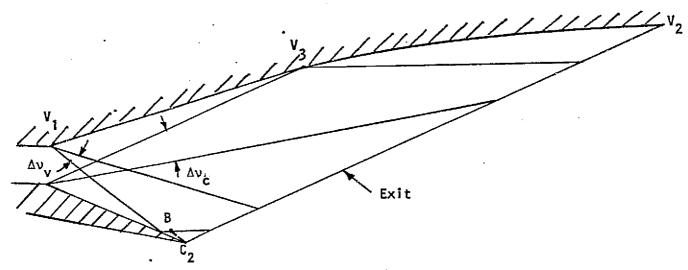


FIGURE 5. PARTIAL REFLECTION OF COWL AND VEHICLE EXPANSIONS

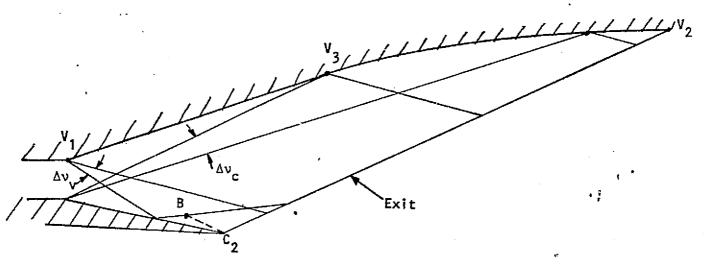


FIGURE 6. COMPLETE REFLECTION OF COWL EXPANSION/ PARTIAL REFLECTION OF VEHICLE EXPANSION

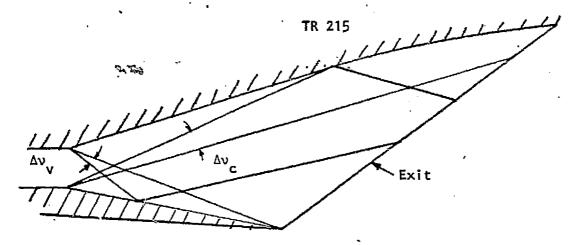


FIGURE 7. PARTIAL REFLECTION VEHICLE EXPANSION/
COMPLETE REFLECTION OF COWL EXPANSION

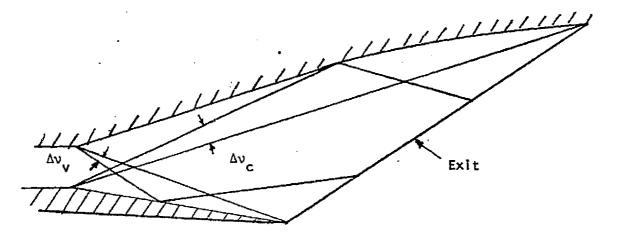


FIGURE 8. COMPLETE REFLECTION OF COWL AND VEHICLE EXPANSIONS

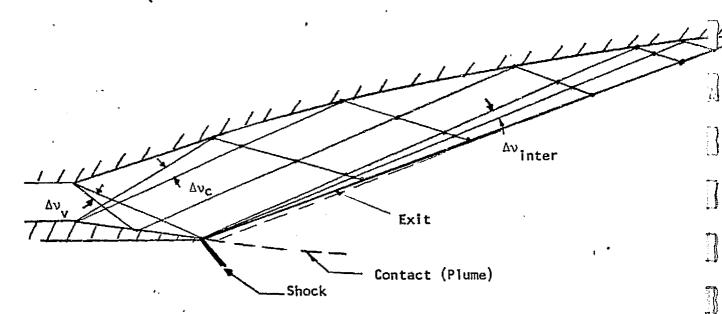


FIGURE 9. INTERACTION OF EXTERNAL FLOW WITH VEHICLE UNDERSURFACE

until zero flow deflection results at point  $V_2$ . The cowl length is now incremented by a specified amount and the complete process repeated. In this manner a parametric map of lift, thrust and pitching moment is generated as depicted in Figures (10) and (11). The dotted lines are the present analysis for a cowl length of 5 and the solid lines were taken from the previous work described in Reference (2).

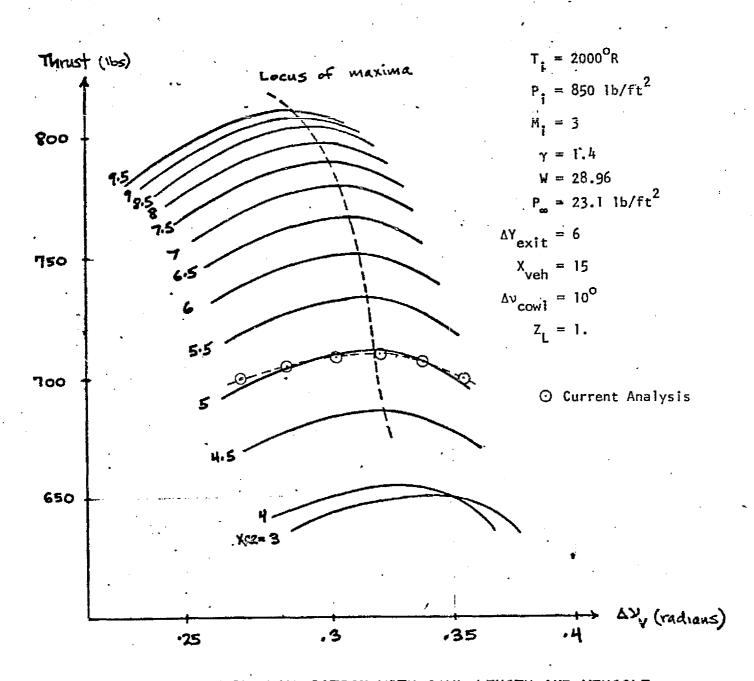
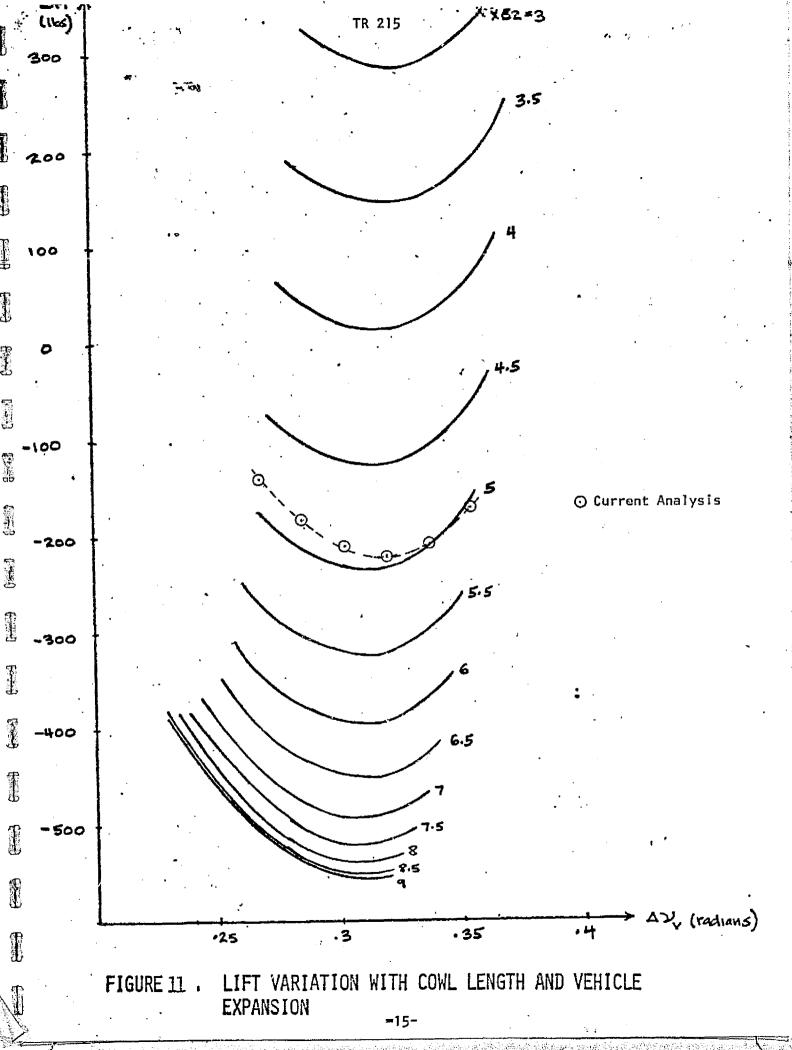


FIGURE 10. THRUST VARIATION WITH COWL LENGTH AND VEHICLE EXPANSION ANGLE



#### SECTION (V

#### THRUST, LIFT AND PITCHING MOMENT

The following definitions are used in this report for thrust, lift, pitching moment

$$T = \int_{A} (p - p_{\infty}) \hat{i}_{x} \cdot dA_{n} + T_{vis}$$
 (18)

$$L = \int_{A}^{(p-p_{\infty})} \hat{i}_{y} \cdot dA_{n}^{+} + L_{vis}$$
(19)

$$M_{y} = + \int x \cdot dL + \int y \cdot dT \qquad (20)$$

Figure (1.2) gives the orientation of the vectors with respect to the vehicle. Internally the integrals range over all the vehicle surface areas. Externally they range over the complete vehicle undersurface as defined by the bounding stream surface and/or flow fence.

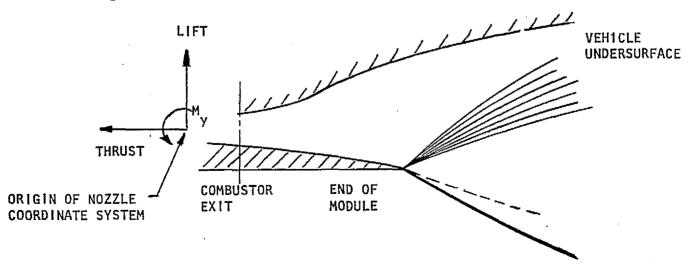


FIGURE 12. THRUST, LIFT, MOMENT

As defined above the nozzle thrust, lift and pitching may include viscous forces. These effects will be discussed below. However, we define  $T_{\rm vis}$ ,  $L_{\rm vis}$  as

$$T_{vis} = -\int_{A} \left(\frac{\rho q^{2}}{2}\right)_{local} c_{f} \hat{i}_{x} \cdot dA_{s}$$
 (27)

$$L_{vis} = - \int_{A} \left(\frac{pq^{2}}{2}\right)_{local} C_{f} \hat{i}_{y} dA_{s}$$
 (22)

Surface Area Computation - Internally the nozzle surfaces are defined as the cowl internal surface, vehicle undersurface, and the nozzle sidewall. Externally the surfaces are defined as the nozzle undersurface and/or flow fences. The lateral extent of the cowl surface and nozzle undersurface is defined by the degree of lateral expansion desired.

It is assumed that the nozzle area can be approximated by a series of elemental quadrilaterals, as shown in Figure (13). From Reference (7) the unit normal for an elemental area may be obtained by defining two surface tangent vectors from the diagonals of the quadilateral.

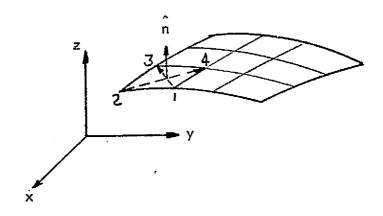


FIGURE 13. ELEMENTAL SURFACE AREA

That is

$$T_1 = T_{1x} \hat{i}_x + T_{1y} \hat{i}_y + T_{1z} \hat{i}_z$$
 (23a)

$$\frac{+}{T_2} = T_{2y} \hat{i}_x + T_{2y} \hat{i}_y + T_{2z} \hat{i}_z$$
 (23b)

where

$$T_{1x} = x_3 - y_2, \quad T_{1y} = y_3 - y_1, T_{1z} = z_3 - z_1$$

$$T_{2x} = x_4 - y_2, \quad T_{2y} = y_4 - y_2, \quad T_{2z} = z_4 - z_2$$

and the normal N is defined as

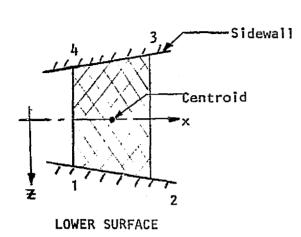
$$\overrightarrow{N} = \overrightarrow{T}_2 \times \overrightarrow{T}_1$$

and the unit normal as

$$\hat{\hat{n}} = \frac{\vec{N}}{|\vec{N}|}$$

A tangent plane is constructed using the normal vector and the two tangent vectors  $\overline{T}_2$ ,  $\overline{T}_1$ . The corners of the surface element are projected onto this plane and the area and centroid of the quadilateral are calculated as described in Reference (7).

Typical nozzle elemental areas are shown in Figures (14) and (15)



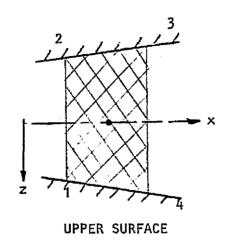
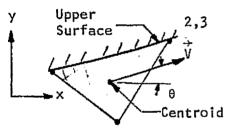
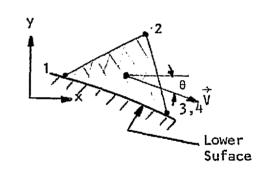
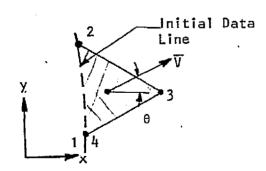


FIGURE 14. UPPER OR LOWER SURFACE AREA ELEMENTS







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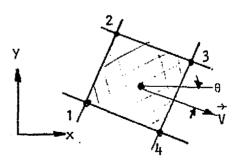


FIGURE 15. SIDEWALL AREA ELEMENTS

#### TR 215 SECTION V VISCOUS EFFECTS

Local skin friction and heat transfer coefficients are computed via curve fit data supplied from Reference (7). These fits are based on the Spalding and Chi method of Reference (4). That is a suitably transformed skin-friction coefficient is given by incompressible formulas based on a suitably transformed Reynolds number, i.e.:

$$c_{f_{\delta}} = c_{f_{i}}/F_{c} \tag{25}$$

$$C_{f_i} = f(Rx_i), Rx_i = F_{Rx} \cdot Rx$$
 (26)

where

 $C_f$  = local skin friction coefficient

Rx = Reynolds number

(); = indicates incompressible

() $_{\delta}$  = indicates compressible

Now for  $Rx_i > 2540$  the local skin friction is given from Reference (8) as

$$C_{f_i} = .088 (\log Rx_i - 2.3686)/(\log Rx_i - 1.5)$$
 (27)

and from Reference (7)

$$F_c = A/\left(ARSIN\left(\frac{A-B}{C}\right) + ARSIN\left(\frac{A+B}{C}\right)\right)^2$$
 (28)

$$A = \frac{H_{AW}}{H_{\delta}} - 1 \tag{29a}$$

$$B = \frac{H_W}{H_S} - 1 \tag{29b}$$

$$c = ((A+B)^2 + 4A)^{1/2}$$
 (29c)

$$F_{Rx} = \left(\frac{H_{AW}}{H_{\delta}}\right)^{q} / \left(F_{c} \left(\frac{H_{V}}{H_{\delta}}\right)\right)^{p+q}, \quad q = 0.772, \quad p = 0.702$$
 (30)

The local properties external to the boundary layer are the local data computed by frozen (NOZD) or equilibrium (NOZDE) programs and are assumed to act through the centroid of the elemental area computed above. The computation requires that a boundary layer origin be specified since the nozzle is assumed to be an extension of the combustor. In addition, a recovery factor for an adiabatic wall calculation is required. However, as a user option wall temperature distributions may be specified.

Local heat transfer coefficients are computed from a modified Reynolds analogy for turbulent flow

$$St = Sh \cdot C_f/2 \tag{31}$$

The program requires "Sh" as an input item.

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TR. 215, SECTION VI CONCLUSIONS

The numerical program developed should be a useful tool in rapidly assessing the affects of varying dominant parameters on scramjet exhaust nozzles. The program has the capability of analyzing a general class of scramjet nozzle configurations. Sophisticated force and moment calculations allow for the inclusion of local viscous affects and accurate computation of lateral forces. In addition, the effects of external flow conditions on nozzle performance may be rapidly assessed as part of the overall procedure. These features make the current program a valuable tool in designing scramjet nozzle configurations.

#### TR 215

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#### APPENDIX 1:

#### PROGRAM DESCRIPTION

NOZD - Frozen Nozzle Design NOZDE - Equilibrium Nozzle Design

#### A. INPUT

Program Control

Card 1	(Format	8E10.0	)	
Column	1-10		PI	(initial pressure, lb/ft <sup>2</sup> )
	11-20		TI	(initial pressure, OR)
	21-30		wl	(initial molecular wt - frozen)
				(initial fuel/air equivalence ratio equilibrium)
	31-40		THI	(initial flow deflection angle, degrees)
	41-50		EM1	(initial Mach number)
*Frozen	Deck			·
	51-60,		GAMI	(initial ratio of specific heats)
	61-70		PINF	(free stream pressure, lb/ft <sup>2</sup> )
*Equilib	orium Deck			
	51-60		PINF	(free stream pressure, Ib/ft <sup>2</sup> )
Card 2	(Format	8E10.0)	)	
Column	1-10		PF	(external pressure, 1b/ft <sup>2</sup> )
	11-20	:	TF	(external temperature OR)
	21-30	•	wf	(external molecular weight)
	31-40	ŕ	THF	(external flow deflection angle, degrees)
	41-50		EMF	(external Mach number)
	51-60	•	GF	(external ratio of specific heats)
Card 3	(Format	8E10.0	)	
Co1 umn	1-10		XVI	<pre>(axial location of throat on vehicle under- surface ft)</pre>
	11-20		I VY	(throat height on vehicle undersurface, ft)
	21-30		XV2	(axial location of vehicle end, ft)

XCI (axial location of throat on cowl surface,

Column 31-40

0014	J	7,01	ft)
	41-50	YCI	(throat height on cowl surface, ft)
	51-60	XC2	(length to end of cowl, ft)
	61-70	DYV	(vehicle exit height, Y <sub>v2</sub> - Y <sub>c2</sub> , ft)
	71-80	DNUC	(Δν <sub>c</sub> - cowl turning angle, degrees)
Card 4	(Form	at 8E10.0)	
Column	1-10	XFI	(axial location of vehicle fence on vehicle undersurface, ft)
Card 5	(Form	at 8E10.0)	
Column	1-10	хнх	(total initial thrust, lbs)
	11-20	XLFT	(total initial lift, 1bs)
	21-30	хмом	(total initial pitching moment, Ib-ft)
•	31-40	ŻVТНХ	(initial viscous thrust, lbs)
	41-50	XVLFT	(initial viscous lift, lbs)
	51-60	MOMVX	(initial viscous pitching moment, lb-ft)
•	61-70	XSHFT	(x-moment axis, ft)
	71-80	YSHFT	(y-moment axis, ft)
Card 6	<u>F</u>	ormat	
Column	1-5	15 ICF	<ul> <li>number of different cowl lengths to be executed</li> </ul>
	6-15	E10.0 . DXC	- increment to be added to original cowl length x <sub>C2</sub>
	16-20 /	15 JFT	<ul> <li>number of vehicle turning angles to be run for each cowl length</li> </ul>
• .	-21-30	E10.0 DTH	- increment for vehicle turning angle in degrees
	31-35	15 IVIS	- option for viscous calculation - 0 if no calculation, 1 for calculation
	36-40	15 IT	- option for wall temperature calculation; O-calculate T wall, 1-adiabatic wall

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(If IVIS is equal to 1 read this card)

Card 6a	(Format	8E10.0)	
Column	1-10	XSTR	(virtual origin of boundary layer, ft)
	11-20	Rec	(recovery factor)
31-40		SH	(constant for Stanton number calculation $St = SH \cdot CF/2$ .)
•	41-50	RT	(throat height, ft)
	(If IT is	equal to 0 i	read this card)

Card 6b	(Format	8E10.0)					•					
Column	1-10		coeffi									
	11-20	BH(1)	Twall	= AH	•	$\chi^2$	+	вн	•	X	+	СН
	21-30	CH(1)	,,,,,,									

Card 7	(Format	8E10.0)	
Column	1-10	AZ	coefficients in equation
	11-20	BZ	$Z = AZ \cdot X^2 + BZ \cdot X + CZ$
	21-30	CZ	•

#### B. OUTPUT

Output variables are printed for each uprunning characteristics ( $C_+$ ) from cowl to vehicle surface or exit plane. In addition, values of thrust, lift and pitching moment are printed as well as the viscous contributions to these values. The value of ideal thrust printed is based on a one dimensional area considerations, assuming  $A_{exit} = (YVZ-YCZ) (ZC_2+ZV_2)/2$ .

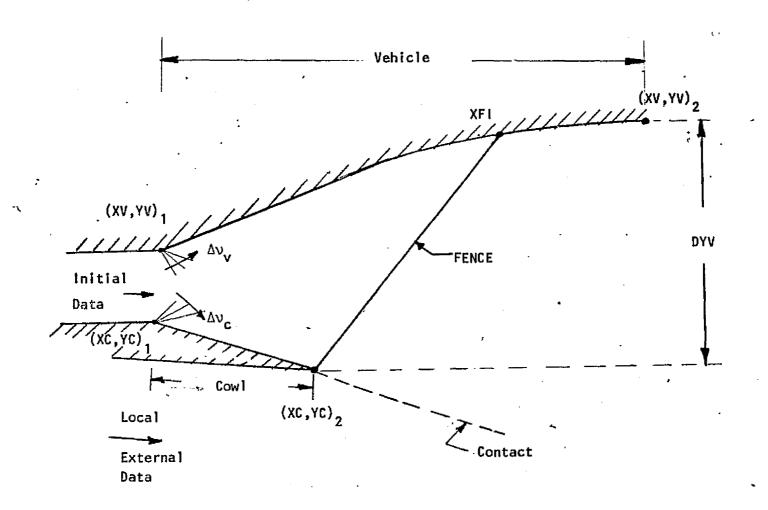


FIGURE 16. GEOMETRIC INPUTS

#### C. SUBROUTINES

- 1. CWALL boundary calculation for cowl surface
- 2. ENDD boundary point for vehicle end (XV2)
- 3. INT interpolation subroutine
- 4. THM computes ideal thrust
- EM3D computes Mach number correction for lateral expansion ideal gas only
- 6. SWITCH- resets initial calculational line
- 7. V<sub>WALL</sub> boundary calculation for vehicle surface
- 8. GEM locations intersection of straight lines
- 9. FIX computes general interior point properties as described in Section i!!
- 10. PM calculates Prandtl-Meyer expansion for given Δν
- 11. GNURE computes skin friction and heat transfer coefficients
- 12. VIS computes viscosity
- SNARF computes elemental area and centroid
- 14. LTHM computes lift, thrust and pitching momen\* for cowl, vehicle and fence surfaces
- 15. ERROR Newton-Raphson method for finding roots
- CNT Commutes local plume shape
- 17. COWL computes underexpansion interaction
- 18. PMI ideal gas Prandtl-Meyer expansion equilibrium program only

#### D. FUNCTIONS

1. GETZ - computes z location via curve  $z = A \cdot X^2 + B \cdot X + C$ (The following are incorporated only into the equilibrium deck)

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- FH computes static enthalpy of equilibrium mixture, H = FH (P, φ, T)
- 3. FT computes static temperature from inversion of function, FH T = FT (P,  $\phi$ , H)
- 4. FGAM- computes equilibrium isentropic component,  $\Gamma = FGAM(T,P,\phi)$
- 5. RHEQ- computes equilibrium mixture density,  $\rho = RHEQ(H,P,\phi,T)$

## APPENDIX II LISTING OF FROZEN FLOW PROGRAM

```
PROGRAM NOZD (INPUT, GUTPUT, TAPES=IRPUT, TAPE6=OUTPUT)
         COMMON/IN/PI, TI, AI, THI, EWI, GAMI, ZI
         CUMMUN/SHF/X3HFT, YSHFT
         COMMON/POL/ IPR, IPOLY
         COMMON/IHRMAX/THRMAX
         CDMMON/X/X(2,50),Y(2,50),Z(2,50),TH(2,50),XNU(2,50),
        1P(2,50),T(2,50),E4(2,50),X4U(2,50),U(2,50)
         COMMON/C/D NUV, DNUC, XC1, YC1, XV1, YV1, DNUL
         COMMONICALIXCS, YCS
COMMON/P/PINE, PIOT, TIOT
         CUMMUN/D3/ AZ, HZ, CZ
         COMMUN/V/AV, BV, CV, XV, XV2, YV2
                                                          RI, SH, II, IVIS
                                               REC.
         COMMUN/HOT/AH(3), SH(3), CH(3), XSTR,
         COMMON/VISF/XVTHX, YVLFT, XVMOM
         COMMON/CP/CP1,GI
                           , RGAS
         COMMON/FRIC/CF(50),ST(50)
         COMMON/F/PF, TF, MF, THF, EMF, GF
         COMMON/CMTC/TTC,PTC,WC,GC,PC,THC,XNUC,ZC,EMC
         DIMENSION HUL(11), HULE(6), DAUE(10)
Z.
         DATA HOLE/2HE0, 2HE1, 2HE2, 2HE3, 2HE4, 2HE5/
         DATA HOL/24V1,2HC1,2HA ,2HB ,2HC ,2HV3,2HC3,2HF ,2HG ,2HV4/
      97 FORMAT(15,8E12.4)
      98 FORMAT(/)
    100 FORMAT(8E10.0)
         0=0.
         LPS=1.E-05
         DO 23 L=1,3
         AH(L)=0.
         BH(L)=0.
      23 \text{ CH(L)} = 0.
         LH=1
         READ(5,100) PI,TI,WI,THI,EMI,GAMI,PINF
         READ(5,100)PF, IF, AF, THF, EMF, GF
         READ(5,100) XV1, YV1, XV2, XC1, YC1, XC2, DYV, DMUC
         READ (5, 100) XF (
         READ(5,100)XTHX,YLFT,XMOM,XVTHX,YVLFT,XVMOM,XSHFT,YSHFT
         READ(5,5921) ICF, DXC, JTF, DIH, IVIS, IT
         IF(IVIS.ER.1)READ(5,100)XSTR,REC,
         IF(IVIS.EG.1.AND.IT.ED.0)READ(5,100)AH(1),BH(1),CH(1)
    5921 FORMAT(15,E10.0,15,E10.0,315)
         XHTX=IXHTX
         YLFTI=YLFT
         XMOMI = XMOM
         XFTVX=IXHTVX
         YV[F1]=YV[=1
         ₩CMVX = I MOMVX
         DNUC=DNUC/57.3
         THI=THI/57.3
         DIH=DIH/57.3
         READ(5,100) AZ,BZ,CZ
         ZC1=GE12(XC1)
         ZV1=GETZ(XV1)
         ZC2=GETZ(XC2)
         ZI = ZVI
         GI=GAMI
         WRITE(6,5922)
    5922 FORMAT (1H17/777)
         wR1TE(6,1020)
                     PUXXER OZEN FLOW
                                                   NOZZLE
                                                                  DESIGNAL
    1020 FURMATO
```

```
wRITE(6,5930) XV1, YV1, XV2, XC1, YC1, XC2, DYV
5930 FORMAI(///6x*xv1*10x*yv1*10x*xv2*1ux*xC1*10x*YC1*10x*xC2*10x*DYV*
    17E13.5///)
1800 FORMAT(*
               THRUST= *F12_5,7X+LIFT = x[13.5,7X+MQME@T= *E13.5)
     WRITE(6,1800)XTHX,YLFT,XMDM
1900 FORMAT(* VISCOUS THRUST= *E13.5,7x*VISCOUS LIFT= *E13.5,7x*
    IVISCOUS MOMENT= *£13.5)
     WRITE(6,1900)XVTHX,YVLFI,XYMOM
     WRITE(6,5923)XSHFT,YSHFT
5925 FDRMAT(9X*MUMEVF AXIS*/12X*X =*E13.5/12X*Y =*E13.5///)
     WRITE(6,1001) AZ,BZ,CZ
1001 FURMAT(9x*LATERAL EXPANSION EQUATION*/9x,22H2(X) = AZ*X**Z+BZ*X+CZ
    1/12X*AZ =*E13.5/12X*HZ =*E13.5/12X*CZ =*E13.5)
     Dum=1.+(GI-1.)/2.*EMI**2
     PTOT=PI *DUM**(G[/(GI-1.))
     TTOT=TI*DUM
     RG=49800.
     RGAS=RG/WI
     CPI=GAMI*RGAS/(GAMI-1.)
     XC55=XC5
     THC1=THI=D NUC
     DO 5000 IXC=1, ICF
     XC2=XC22+FLOAT(IXC=1)*DXC
     CALL THM(EMI, PI, GI, PINF, YV1, YC1, DYV, XV2, THRMAX, XC2, ZI)
     WRITE (6,6304) THR MAX
6364 FURMAT(1H131X*IDEAL THRUST =*E12.4)
     YC2=YC1+TAV(THC1)*(XC2-XC1)
     1452153A
     THC=ATAN((YC2-YC1)/(XC2-XC1))
     DO 6000 JT=1,JTF
     XIHX=XIHXI
     YLFT=YLFTI
     I M O M X = M O M X
     XVTHX=XVTHXI
     YVLFI=YVLFTI
     I MOMVX=MOMVX
     KSTP=50
     1STP=50
     IEND=0
     IEXT=0
     If LG=0
     IND=0
     THX=1.E+10
     THJ1=FLDAT(JT-1)*DTH
     TLHT+IHT-((IVX-SVX)\(IVY-SVY))MATA=VUND
     WRITE(6,1894) DNUV
1894 FORMAT(* VEHICLE EXPANSION = *E13.5)
     XV = XVI
     AV = YV1
     BV=TAN(THI+DNUV)
     C V = 0 .
     YF1=AV+BV*(XF1=XV)
     IDUM=DNUV*57.3
     IF(IDUM.GT.11) IDUM=11
     IF (IDUM.EQ.O) IDUM=1
     DELNU=DNUV/FLOAT(IDUM)
     IDUM=IDUM+1
     NUC1=XAMI
     KMAX=IMAX+2
     DO 10 I=1, IMAX
     X(1,1)=XV1
     Y(1, I) = YVi
     Z(1,1)=GETZ(XVI)
     TH(1,1)=THI+FLDAT(I-1)*DELNU
                       ina di kanangan mangan salangan kanangan salangan kanangan kanangan kapan kanangan kanangan kanangan kanangan
```

```
10 CONTINUE
         IDUM=DNUC*57.3
         IF (IDUM.GT.11) IDUM=11
         IF(IDUM.EQ.0) [DUM=1
         DELNU=DNUC/FLOAT(IDUM)
         I+MUGI=MUGI
         X(2,1) = XC1
         Y(2,1) = YC1
         Z(2,1)=GETZ(XC1)
         ICWL=0
         I = 1
         THII=THI
         XVUI=0.
      20 CONTINUE
         TH(2,1)=THII-FLUAT(I-1)*DELNU
         XNU(2,1)=FLOAT(I-1)*DELNU+XNUI
         CALL PM(2,1)
      22 CONTINUE
         K=2
      36 CONTINUE
         IF (K.LT.KMAX) GO TO 41
         IF (IEND, EQ. 1) GO TO 53
         CALL VWALL (IMAX, KMAX)
         MM=K+1
         L=K-i
         IF (ICWL, EQ. 1) L=K
          IF(X(2,K).LI.XV2-EPS)GO TO 24
          CALL ENDD(L,MM,KMAX)
         X(5,K)=XVS
          IF (KSTP.GE.KMAX)KSTP=KMAX
          INDET
          GO TO 17
      24 IF (I.GT.1) GU TU 30
          AV=Y(2,KMAX)
          BV=TAN(TH(2,KMAX))
          CV = (AAS - VARANTAN + (XAS - X(S + WWX))) / (XAS - X(S + WWX)) **
          [HV2=ATAN(3V+2.*CV*(XV2-X(2,KMAX)))
          XV = X(2,KMAX)
1
            IF(XF1.GT.XV)YF1=AV+BV*(XF1-XV)+CV*(XF1-XV)**2
          SLE=(YF1-YC2)/(xF1-xC2)
          IF(|HV2.LT.0.) GU TU 462
          DO 16 KT=2,KMAX
          XK1=XK2=XK3=XK4=0.25
          M=KI-1
          J=KT-I
          ∿=J
          IF (KT.EU.KMAX) J=KT-2
          IE(K1°E0°S°OS°K1°E0°KWVX) N=1
          TF(KT.EU.2.JR.KT.EU.KMAX)XK3=0.
          IF(K1.E0.2.OR.K1.E0.KMAX)XK1=XK2=XK4=.333333
          CALL LIHM(X(2,M),Y(2,M),Z(2,M),X(1,N),Y(1,N),Z(1,N),X(1,J),
         1Y(1,J),Z(1,J),X(2,KT),Y(2,KT),7(2,KT),P(2,M),P(1,M),P(1,J),
         2P(2,K1),0(2,M),0(1,N),0(1,J),0(2,K1),1(2,M),1(1,N),1(1,J),
         3T(2,KT),TH(2,M),TH(1,N),TH(1,J),TH(2,KT),XK1,XK2,XK3,XK4,1.,
         TXTHX, YLF1, X NOM, CF(M), ST(M), 3)
          IF(Ki.EQ.KMAX)
         ICALL LTHM(X(1,J),Y(1,J),Z(1,J),X(1,J),Y(1,J),O.,X(2,KT),Y(2,KT),O.
         2,X(2,KT),Y(2,KT),Z(2,KT),P(1,J),P(1,J),P(2,KT),P(2,KT),Q(1,J),
         30(1,J), G(2,KT), G(2,KT), T(1,J), T(1,J), T(2,KT), T(2,KT), TH(1,J),
         4TH(1,J),TH(2,KT),TH(2,KT),.25,.25,.25,.25,1.,XTHX, YLFT, XMUW,
         SCFU, STU, 1)
       16 CONTINUE
          GO TO 53
```

```
IF (ICNL. EQ. 1. AND. K. EQ. 2. AND. IEXT. EQ. 1) CALL CHT
    L=K
    IF (ICWL.EQ.1)L≈K+1
    IF(I.EQ.1) L =K-1
    LM=L-1
    LL=K+ICWL-1
    IF(L
           .GT.ISTP.AND.IEND.EQ.1)GO TO 30
    MM=K-1
    CALL FIX(2,K-1,1,L ,2,K)
    1f(1.Eq.1)SQ TO 30
    IF (K,GT,1)SLA=(1(2,K)=Y(2,KM))/(X(2,K)=X(2,KM))
    CALL GEM(X(2,MM),Y(2,MM),SLA,XC2,YC2,SLE,XC,YC)
    IF(XC.GE.X(2,K) .OR.XC.LT.X(2,NM)-EPS)GO TO 30
    KSTP=K
    WRITE(6,88)KSTP, ISTP, KNAX, IMAX
 88 FORMAT(1x,415)
 30 CONTINUE
    LM=L-1
    IF(I.E0.1)GO T033
    IF (IEXT.EQ.1)GO TO 32
    IF (ICNL.ED. U.OR.K.GT.2)GO TO 32
    CALL LTHM(X(1,1),Y(1,1),Z(1,1),X(2,1),Y(2,1),Z(2,1),X(2,1),
   1Y(2,1),0.,X(1,1),Y(1,1),0.,P(1,1),P(2,1),P(2,1),P(1,1),Q(1,1),
    20(2,1),0(2,1),4(1,1),T(1,1),T(2,1),T(2,1),T(1,1),TH(1,1),IH(2,1),
    3TH(2,1),TH(1,1),.25,.25,.25,.25,1.,XTHX, YLFT, XMOM,CFL,STL,2)
    CALL LTHM(X(1,1),Y(1,1),Z(1,1),X(1,2),Y(1,2),Z(1,2),X(2,1),Y(2,1),
    1Z(2,1),×(2,1),Y(2,1),Z(2,1),P(1,1),P(1,2),P(2,1),P(2,1),Q(1,1),
    20(1,2),6(2,1),0(2,1),7(1,1),7(1,2),7(2,1),7(2,1),7H(1,1),7H(1,2),
    3TH(2,1),TH(2,1),.33333,.33333,.33333,0.,1.,XTHX, YLF1, XNDM,
    4CF(1),ST(1),3)
 32 CONTINUE
    XK1=XK2=XK3=XK4=.25
    IF ( LEND . EQ . O . AND . K . EQ . KMAX ) GO TO 17
    AVG=4.
    SLB=(Y(2,K)=Y(1,L))/(X(2,K)=X(1,L))
    CALL GEM(X(1,L),Y(1,L),SLB,XC2,YC2,SLE,XC,YC)
    RAT = (XC - X(1,L))/(X(2,K)-X(1,L))
    IF(RAT.GT.0.99)GO TO 144
    IF (RAT.GT.0.)GO TO 143
    AVG=2.
    GO TO 144
143 AVG=AVG-1.
144 CONTINUE
     IF((X(2, MM)-X(1, LM)), E0.0, )GOTO 148
    SLB=(Y(2,VV)-Y(1,LF))/(X(2,FV)-X(1,LF))
    CALL GEM(X(1,LM),Y(1,LM),SLB,XC2,YC2,SLE,XC,YC)
    RAT = (XC - X(1, LM))/(X(2, M)) - X(1, LM))
     IF (RAT.GT.0.99) GO TO 148
    IF (RAT.GT.U.) GU TU 145
     AVG=AVG-2.
    GO 10 148
145 AVG=AVG-1.
V148 CONTINUE
   · AVG=AVG/4.
    CALL LIHM(X(2,MM),Y(2,MM),Z(2,MM),X(1,LM),Y(1,LM),Z(1,LM),X(1,L),
    1Y(1,L),Z(1,L),X(2,K),Y(2,K),Z(2,K),P(2,MM),P(1,LM),P(1,L),P(2,K),
    20(2,MM),0(1,LM),0(1,L),0(2,K),7(2,KM),1(1,LM),1(1,L),1(2,K),
    3TH(2,MM),TH(1,LM),TH(1,L),TH(2,K),XK1,XK2,XK3,XK4,AVG,XTHX, YLFT,
   4XMOM, CF(LL), ST(LL), 3)
    IF (IEND.EQ. 1. OR.K.LT.KMAX) GO TO 33
 17 CONTINUE
    M=K-1
    [=M
     IF(ICUL_EO.1)L=K
```

```
CALL GEM(X(2,M),Y(2,M),SLA,XC2,YL2,SLE,XC,YC)
      RAT=(XC-X(2,M))/(X(2,K)-X(2,M))
       IF (RAT.GT.0.99) GO TO 177
       AVG=AVG-1.
  177 SLB=(Y(2,A)-Y(1,L))/(X(2,M)-X(1,L))
      CALL GEM(X(1,L),Y(1,L),SLB,XC2,YC2,SLE,XC,YC)
       RAT=(XC-x(1,L))/(x(2,N)-x(1,L))
       IF(RAT.GT.0.99)GD TO 178
       IF (RAT.GT.O.)GU TU 173
       AVG=AVG-2.
# 173 AVG=AVG-1.
  178 CONTINUE
      AVG=AVG/3.
       CALL LIHM(x(2,M),Y(2,M),Z(2,N),X(1,L),Y(1,L),Z(1,L),X(2,K),Y(2,K),
      1Z(2,K),X(2,K),Y(2,K),Z(2,K),P(2,M),P(1,L),P(2,K),P(2,K),U(2,M),
      20(1,L),0(2,K),Q(2,K),T(2,K),T(1,L),T(2,K),T(2,K),TH(2,K),TH(1,L),
      3TH(2,K), TH(2,K), . 33333, . 35333, . 35333, 0., AVG, XTHX, YLFT, XMDM,
      4CF(LL), ST(LL), 3)
   45 CALL LTHM(X(1,L),Y(1,L),Z(1,L),X(1,L),Y(1,L),O.,X(2,K),Y(2,K),
      10.,X(2,K),Y(2,K),Z(2,K),P(1,L),P(1,L),P(2,K),P(2,K),Q(1,L),Q(1,L),
      20(2,K),0(2,K),1(1,L),1(1,L),1(2,K),1(2,K),TH(1,L),1H(1,L),1H(2,K),
      3TH(2,K),,25,.25,,25,,25,1.,XTHX, YEFT, XMOM,CFU,<u>$</u>TU,1)
   33 IF (IEND. EQ. 1) KWAK= ISTP
       K=K+1
       IF (K.LE.KMAX)GO TO 36
   53 KP=KMAX
       IF (IEND, EG. 1) KP=KMAX=1-ICWL
       1F (IND, EQ. 1; 1END=1
       "O=GNT
59
       WRITE (6,6895)
$ 6885 FORMAT (1xxPT, *ox*x*11x*Y*8x*PRESSURE*5x*ANGLE*8x*MACH*4x*TEMPERATO
      1RE*1X*PM FUVCTION*3X*VELOCITY*)
       00 50 L=1,KP
       WRITE(6,97) L,X(2,L),Y(2, L),P(2,L),TH(2,L),EM(2,L),T(2,L),XNU(2,
      IL),0(2,L)
    50 CALL SMITCH(2, L, 1, L)
       WRITE(6,2001)CFU,STU,CFL,STL
2001 FORMAT(* VEH. FRIC. COFF= *E13.5,2x*VEH. STANTON NUM.= *E13.5,2x*
      1 CONL FRIC. COEF. = *E13.5,2X*CUVL STANTON GUM. = *E13.5)
       WRITE (6,450)
       NPR1=1M4X/5
       DO 166 K=1, NPR1
       K1=K&K2=K1+NPR1&K3=K2+NPR1&K4=K3+NPR1&K5=K4+NPR1
       KUUNE=KS
       WRITE(6,500)CF(K1),ST(K1),CF(K2),ST(K2),CF(K3),ST(K3),
      1CF(K4),ST(K4),CF(K5),S1(K5)
   166 CONTINUE
       IF (KOONE EQ. IMAX) GO TO
       NPR2=5*NPP[+]
       DO 414 K=NPR2, IMAX
       WRITE(6,550)CF(K),ST(K)
   414 CONTINUE
   55 CONTINUE
   450 FORMAT(1X,5(6X,*CF *,9X,* ST
   500 FORMAT (1x, 10E13.5)
   550 FORMAT(105x, 2E13.5)
       WRITE (6,98)
       WRITE(6,1800)XTHX,YLFT,XMOM
       WRITE(6,1900)XVTHX, YVLFT, XVMOM
       IMAX=KMAX
       I≓I+ľ
       IF (1.GT.IDUM) ICaL#1
       IF (ICNL_EN_U)KMAX=KMAY+1
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From the case to be commented by the challenges as a construction between the constructions and the construction of the constr

	IF(IEXT.EG.O.AND.X(1,1).GE.XC2-EPS)GU TO 5900	
	TE (IEV)*E8*0*440*V(INI)*BE*VOS = E O OOO	
	IF(ICWL.EG.1)GU 10 22	<b>-</b>
n 4 3	GO TO 20 CONTI 4UE	)
402	WRITE(6,992)	1
00.3	FORMAT(ATHV2.LT.Ox)	
776	GO TO 6000	
5000		į
2400	COMITAGE  IF(P(1,1).LE.PF)GO TO 5396	•
	CALL COWL(DNUE)	• !
	I=2 X%UI=XNU(1,1)	
		1
<del></del>	THII=TH(1,1) ICHL=0	- 1
	KMAX=KMAX+1	
	DELNU=DNUE/FLUAT(IDUM)	1
		1
	IDUM=IDUM+1 IEXT=1	
	GO TO 20	
5707	CONTINUE	-
	CONTINUE	
	CONTINUE	
2000	END	í
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SUBROUTINE CWALL (IMAX, KNAX, KSTP, ISTP)
   COMMON/x/x(2,50),Y(2,50),Z(2,50),TH(2,50),XNU(2,50),
  1P(2,50), T(2,50), EM(2,50), XMU(2,50), Q(2,50)
   COMMON/C/ONUV, DNUC, XC1, YC1, XV1, YV1, DMUL
   COMMON/CAL/XC2,YC2
   IADD=0
   LUOPER
   X[H^{A}]=[H(1,1)-X^{A}\cup(1,1)
   Q1 = XNU(1,1) = TH(1,1)
   CALL INT(0., X(1,2), Y(1,2), Z(1,2), Th(1,2), XNU(1,2), P(1,2), T(1,2),
  1EM(1,2),xMU(1,2),D,D,D,D,D,D,D,D,D,XA,YA,ZA,THA,xNUA,PA,TA,
  2EMA, XMUA, -1.)
   02=XMU(1,2)=TH(1,2)
44 X1442=1HA-X MUA
   IF(LOUP.EQ.O)XTHM3=XTHM2
   SLA=(TAN(XTHM2)+[AN(XTHM3))/2.
  ·SLB=(YC2-YC1)/(xC2-XC1)
                            ,SLA, XC2, YC2, SLB, XC, YC)
   CALL GEM(XA
                    YA
   1F(XC.LE.XC2)G0 TO 43
   1ADD=1
   D \times = \times (1,2) - \times (1,1)
   SLU=(Y(1,2)-Y(1,1))/DX
   IT=1
   XA = (X(1,2) + X(1,1))/2.
24 RAT = (xA - x(1,1)) / Dx
   SLB=XTHH1+RAT*(XTHM2-XTHM1)
   SLB=TAN(SLB)
   IF (LOOP, EQ. 1) SUB=(SUH+TAN(XTHM3))/2.
   CALL GEM(X(1,1), Y(1,1), SLU, XC2, YC2, SLB, XAT, YA)
   ER=ABS((XA-XAT)/DX)
   IF(ER,LT.1.E=04)GO TO 63
   IT=11+1
   IF(IT.GT.10)G0 TO 68
   XA=XAT
   GN TO 24
68 WRITE(6,38)
38 FORMAT(* TOO MANY ITER IN CHALL *)
   WRITE(6,39) LOUP, SLU, SLB, XA, XAT
39 FORMAT(1X, 15, 5013.5)
   STOP
63 CONTINUE
   XC = XCS
   YC=YC2
   IMEIMAXŦI
   X(1,IM)=XA
   Y(1,1,1) = YA
   Z(1,IM) = GETZ(XA)
   XNU(1, [M) = X VU(1,1) + RAT * (XNU(1,2) - XNU(1,1))
   @A=01+RAT*(02=01)
   AG = (MI,I) \cup X \times (MI,IM) = GA
   CALL PM(1, IM)
   CALL INT(0., X(1, 1M), Y(1, 1M), Z(1, 1M), TH(1, 1M), XNU(1, 1M), P(1, 1M),
  1T(1,1M),EM(1,1M),XMU(1,1M),D,D,D,D,D,D,D,D,D,D,XA,YA,ZA,THA,XMUA,
  2PA, TA, EMA, X MUA, [.)
43 RA#THA+XNUA
   IF(ABS(xC2-xC).LE.,0001)XC=xC2
   X(2,1)=XC
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was an order or grant or the contract of the c	
CALL PM(2,1)	
XTHM3=TH(2,1)-XMU(2,1)	
IF(LOUP,EQ.1)GO TO 6	1
LOOP=1	
GO TO 44	
6 IF (IADD.EQ.O)RETURN	
IMAX=IMAX+1	
KMAX=KMAX+1	11
KSTP=KSTP+1	
1STP=ISTP+1	
DO 46 JJ=3, IMAX	
LJ=IMAX-JJ+3	· · · · · · · · · · · · · · · · · · ·
L1=LJ=1	1 \
46 CALL SWITCH(1,L1,1,LJ)	
WRITE(6,181) IADD, XA, X(1,1), X(1,2)	I, i
181 FURMAT (1x, 15, 3E13.5)	
CALL INT(O., XA, YA, ZA, THA, XNUA, PA, TA, EMA, XMUA, D,	D.D.
1X(1,2),Y(1,2),Z(1,2),TH(1,2),XNU(1,3),P(1,2),T(1,2),EM(1,2).	
2xMU(1,2),-1.)	· · · · · · · · · · · · · · · · · · ·
RETURN	
END	·····
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SUBROUTINE ENDO(L, KK, K6)
         COMMON/V/AV, BV, CV, XV, XV2, YV2
         COM 10 1/x/x(2,50), Y(2,50), Z(2,50), TH(2,50), XNU(2,50),
        1P(2,50),1(2,50),EM(2,50),XMU(2,50),@(2,50)
11=1
         B=0.
         A=1.
         XM1=TH(1,L)+XMU(1,L)
         XMS=14(5,KX)+X40(2,KK)
         XM3≈0.
         Q1=1H(1,L )+XNU(1,L )
         Q2=TH(2,KK)+XNU(2,KK)
         XA = (X(1,L) + X(2,KK))/2.
         0x=x(2,KK)-x(1,L)
         SLM=(Y(2,KK)-Y(1,L))/DX
I
      12 RAT=(XA=X(1,L ))/DX
         SLP=XM1+RAT*(XM2=XM1)
         SLP=A*SLP+3*XM3
         CALL GEM(X(1,L ),Y(1,L ),SLM,XV2,YV2,SLP,XAT,YA)
         ER=ABS((XA-XA1) /DX)
         IF (ER.LT.1.E-03)GO 10 14
         I | = I T + 1
         IF(II.LE.10)GU TO 8
         wRITE (6,33)
      33 FORMAT (* TOO MANY ITER IN END *)
         WRITE(6,34)L,KK,K6,XA,XAT,X(2,KK),X(1,L),SLP,XM3
      34 FURMAT(1X, 315, 6E13.5)
         STOP
       B XA=XAT
         GO TO 12
      14 GA=GI+RAT*(32-G1)
         TH(1,L +2)=TH(1,L )+RAT*(TH(2,KK)+TH(1,L ))
         XNU(1,L+2)=UA-TH(1,L+2)
         Z(1,L +2)=GETZ(XA)
         CALL PM(1,
                          L +2)
         RA = XNU(1, L +2) - TH(1, L +2)
         X(5'KP)=X\Lambda5
         Y(5,K6)=YV2
         Z(2,K_0) = GETZ(XVZ)
         TH(2,K6)=ATAN (BV+2.*CV*(XV2-XV))
         XNU(2,K6) = RA + In(2,K6)
         CALL PM(2, K6)
         IEMD=T
          IF (B.GT.O.) RETURN
         TTET
         8=.5
          A=.5
          XM3=TH(2,K6)+XMU(2,K6)
          GO TO 12
         END
```

01=ANU1+OPT*TH1 02=ANU2+OPT*TH1 02=ANU2+OPT*TH2 X3=X1+RAT*(X2-X1) Y3=Y1+RAT*(X2-X1) Y3=Y1+RAT*(Y2-Y1) 03=01+RAT*(X2-01) P5=P1+RAT*(P2-P1) T3=T1+RAT*(Z-T1) EN3=EAT*(X2-X001) TXNU3=XNU1+RAT*(XNU2-X001) TX3=CYNU3-XNU3-XNU1+RAT*(XNU2-X001) TX3=CYNU3-XNU3-XNU3-XNU3-XNU3-XNU3-XNU3-XNU3-X	1x2, y2, z2, [42, xNU2, F2, 12, EM2, 2EM3, x MU3, OPT)	XMU2, X3, Y3, Z3, TH3, XMU3, P3, T3,
Q2=XNU2+OPT*TH2 X3=X1+RAT*(X2-X1) Y3=Y1+RAT*(Y2-Y1) Q3=Q1+RAT*(W2-Q1) P3=P1+RAT*(W2-Q1) EM3=EM1+RAT*(EM2-EM1) XNU3=XNU1+RAT*(XNU2-XNU1) TH3=(U3-XNU3)/OPT XMU3=ASIM(1./EM3) Z3=GETZ(X3) RETURN END		
Y3=Y1*RAT*(J2=Y1) U3=Q1+RAT*(J2=Y1) P3=P1+RAT*(P2=P1) T3=T1+RAT*(T2-T1) EM3=EM1+RAT*(EW2=EM1) XNU3=XNU1+RAT*(XNU2-XNU1) TH3=(U3-XNU3)/OPT XMU3=ASIN(1-/EM3) Z3=GETZ(X3) RETURN END		
Q3=Q1+RAT*(D2=Q1) P3=P1+RAT*(P2=P1) T3=T1+RAT*(T2-T1) EM3=EM1+RAT*(EM2=EM1) XNU3=XNU1+RAT*(XNU2=XNU1) TH3=(U3-XNU3)/DPT XMU3=ASIN(1./EM3) Z3=GETZ(X3) RETURN END	X3=X1+RAT*(X2-X1)	
P3=P1+RAT*(P2-P1) T3=T1+RAT*(T2-T1) EM3=EM1+RAT*(EW2-EM1) XNU3=XNU1+RAT*(XNU2-XNU1) TH3=(U3-XNU3)/OPT XMU3=ASIN(1./EM3) Z3=GETZ(X3) RETURN END		
T3=T1+RAT*(T2-T1)  EM3=EM1+RAT*(EM2-EM1)  XNU3=XNU1+RAT*(XNU2-XNU1)  TH3=(U3-XMU3)/OPT  XMU3=ASIN(1./EM3)  Z3=GETZ(X3)  RETURN  END		
EM3=EM1+RAT*(EM2-EM1)  XNU3=XNU1+RAT*(XNU2-XNU1)  TM3=(W3-XNU3)/OPT  XMU3=ASIN(1./EM3)  Z3=GETZ(X3)  RETURN END		
XNU3=XNU1+RAI*(XNU2-XNU1) TH3=(U5-XNU3)/OPT XMU3=ASIN(1-/EM3) Z3=GETZ(X3) RETURN END	EM3=EM1+RAT*(EM2-EM1)	
XMU3=ASIN(1./EM3) Z3=GETZ(X3) RETURN END	(1UNX=SUNX)*TAF+1UNX=EUNX	
Z3=GETZ(X3) RETURN END		
RETURN END		
END		
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SUBROUTINE THM(EM1, P1, G, PINF, YV1, YC1, DYV, XV2, THRMAX, XC2, ZI)
   A1=YV1-YC1
   A1=A1*ZI
   Z1=GETZ(XV2)
   Z2=GLTZ(XC2)
   A2=DYV*(21+22)/2.
   FM1=1.+(G-1.)/2.*EM1**2
   Dum=(2,*FM1/(G+1.))**((G+1.)/2./(G-1.))
   AST=A1*EMI/DUM
   PIOT=P1/FM1**(G/(1.=G))
   EM2=EM1+SGRT (A2/A1)
   IF (EM1.GT.3.) EM2= (A2/A1) **.3*EM1
   AF=AZ/ASI
   Iiw=0
10 CUNTINUE
   FM2=1.+(G=1.)/2.*EM2**2
   DUM=(2.*FM2/(G+1.))**((G+1.)/2./(G-1.))
   AFT=DUM/EM2
   ERA=(AFI-AF)/AF
   IF(ABS(ERA).LT.1.L-03) GO 10 20
   CALL ERROR(2000, ITM, EM2, ERA, 1.1, EM21, ERA1)
   GO TO 10
20 CUNTINUE
   F1=P1*A1*(1.+G*E11**2)
   P2=FM2**(G/(1.-G))*P101
   F2=P2*A2*(1.+G*EM2**2)
   THRMAX=F2-F1-P1NF*(A2-A1)
   RETURN
   END
```

	SUBROUTINE EM3D(EM, EMX, X, G, Z, ZI)	
	GN=(G+1.)/(G-1.)/2.	<del></del> .
	Y=(1.+(G-1.)/2.*EM*EM)**GN	
	Y=Y/EM/((G+1.)/2.)**GN A=Y*Z/ZI	
	EMX=EM*SURT(Z)	
	ITM=1	—
10	AT=(1.+(G-1.)/2.*EMX*EMX)**GN	•
<u>=</u>	AT=AI/EMX/((G+1.)/2.)**GN	
	ERM=(AT-A)/A	
	IF(ABS(ERM).LT.1.E-03) GO TO 20	
	CALL ERROR(10, ITM, EMX, ERM, 1, 1, EMX1, ERM1)	
20	GO TO 10	
20	CONTINUE RETURN	:
	END	
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	SUBRUUTINE SWITCH(12,K,)1,L) COMMON/X/X(2,50),Y(2,50),Z(2,50),TH(2,50),XNU(2,50),
1	1P(2,50),[(2,50),EM(2,50),XMU(2,50),Q(2,50) X (I1,L)=X (I2,K) Y (I1,L)=Y (I2,K)
1	Z (I1,L)=Z (I2,K) TH (I1,L)=TH (I2,K) XNU(I1,L)=XUU(I2,K)
	P (II,L)=P (I2,K) T (I1,L)=[ (I2,K) EM (II,L)=EM (I2,K) XMU(I1,L)=XMU(I2,K)
	Q(11,L)=Q(12,K) RETURN
Fried -	END
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FUNCTION GETZ(X)	
COMMON/D3/ AZ,BZ,CZ GETZ=AZ*X**2+BZ*X+CZ	
RETURN END	
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SUBROUTINE VWALL (IMAX, KMAX)
  COMMON/X/X(2,50),Y(2,50),Z(2,50),TH(2,50),XNU(2,50),
  IP(2,50), T(2,50), EM(2,50), XMU(2,50), Q(2,50)
  COMMON/V/AV, BV, CV, XV, XV2, YV2
  COMMON/C/DVUV, DNUC, XC1, YC1, XV1, YV1, DNUL
   IBEG=0
   1 I N=1
   SL2=TH(1, IMAX)
   SLI=TAN(TH(2,KMAX=1)+XMU(2,KMAX=1))
   SL13=SL1
   CALL GEM(X(2,KM4X-1),Y(2,KMAX-1),SL1,X(1,IMAX),Y(1,IMAX),SL2,
  IXG, YG)
12 Y#=AV+BV*(XG-XV)+CV*(XG-XV)**2
   ERW=(YW+YG)/(YV1-YC1)
   IF(ABS(ERW).LT.1.E-02) GO TO
   CALL ERROR(1, ITN, XG, ERW, 9, XC1, ER#1)
   YG=Y(2,KMAX-1)+SL13*(XG-X(2,KMAX-1))
10 TH(2,KMAX)=ATAN(BV+2.*CV*(XG-XV))
   XNU(2,KMAX)=TH(2,KMAX)=TH(2,KMAX=1)+XNU(2,KMAX=1)
   X(2,KMAX)=XG
   Y(2,KMAX) #YG
   Z(2,KIAX)=GLTZ(XG)
   CALL PM(2, KMAX)
   IF (IBEG. Ed. 1) RETURN
   IBEG=1
   SL13=.5*(SL1+1AN(TH(2,KMAX)+XMU(2,KMAX)))
   GO TO 12
   END
```

YC=YA+SLA*	SLA*XA-SL&*XB)/(SL (XC-XA)	<u> </u>		
RETURN END				
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SUBROUTINE ERROR (I, IT, X, FR, F, X1, ER1) 11=1T+1 IF(11.L1.15) GO TO 12 WRITE(6,13) I3 FORMAT (\*ERROR TEST NUMBER \*) WRITE (6,20) I 20 FORMAT(15) STOP 12 IF(II.GT.2) GO TO 14 ER1=ER XI=X X = X \* FIF(X,E0,X1) X=X+,02 RETURN 14 XD=X1-ER1\*(X-X1)/(ER-ER1) ER1=ER X1 = XX=XD RETURN END

```
SUBRUUTINE FIX(11, K1, 12, K2, 13, K3)
  CDMMDN/X/X(2,50),Y(2,50),Z(2,50),TH(2,50),XNU(2,50),
  1P(2,50),T(2,50),EM(2,50),XMU(2,50),W(2,50)
   DUM3=0.
   DUM4=0_
  A=1.
   B=U.
   DUM1=TAN(TH(I1,K1)+XMU(I1,K1))
  DUM2=1AN([H(12,K2)-XMU(12,K2))
10 IF(B.GT.O.) DUMS=TAN(TH(13,K3)+XMU(13,K3))
   IF(B.GT.O.) DU44=TAN(TH(13,K3)-XMU(13,K3))
   SL1=A*DU41+B*DU43
   SL2=A*DUM2+B*DUM4
  CALL G: M(X(I1,K1),Y(I1,K1),SL1,X(I2,K2),Y(I2,K2),SL2,X(I3,K3),
  1Y(13,K3))
   Z(13,K3)=GETZ(X(13,K3))
   XNU(13,K3)=.5*(xNU(11,K1)+XNU(12,K2)+TH(12,K2)=TH(11,K1))
   TH(I3,K3) = .5*(xNU(I2,K2) = xNU(I1,K1) + TH(I2,K2) + TH(I1,K1))
   CALL PM(13,K3)
   IF(B.GT.O.) RETURN
   A=.5
   B=.5
   GO TO 10
   END
```

```
SUBROUTINE PM(IX,KX)
        COMMON/IN/PI, TI, NI, THI, EMI, GAMI, ZI
         CDMMUN/X/X(2,50),Y(2,50),Z(2,50),TH(2,50),XNU(2,50),
        1P(2,50),T(2,50),EM(2,50),XMU(2,50),Q(2,50)
         COMMON/P/PIMF, Plot, Troi
         CO-MUN/CP/CPI,GI ,RGAS
         DNU=XNJ(IX,KX)
         G=GI
         EMI=EMI
         GG=SORT((G+1.)/(G-1.))
         XM1=SURT(EM1**2-1.)
         XNU1=GG*ATAN(XM1/GG)-ATAN(XM1)
         EM2=DNU/(1.5-XNU1)*(6.-EM1)+EM1
Ŧ
         I 13=1
      10 XM2=SURT(E42**2-1.)
         DNUT=GG*(ATAN(\timesM2/GG)-ATAN(\timesM1/GG))+ATAN(\timesM1)-ATAN(\timesM2)
        ERNU=DNU-DNUT
         IF(ABS(ERNU).LI.1.E-04) GO TO 20
         CALL ERROR (3, 173, EM2, ERNU, 1, 11, EM21, ERNU1)
         GO TO 10
     SO CONTINUE
         CALL EM3D(EM2, EMX, X(IX, KX), G, Z (IX, KX), ZI)
         P(Ix, KX)=PTUT/(1.+(G-1.)/2.*t Mx**2)**(G/(G-1.))
         T(IX,KX)=TTOT/(1,+(G~1,)/2,*64/X**2)
         EM(IX,KX)=EMX
         XMU(Ix,KX)=ASIN(1./EMX)
         AX=SURT(G*~GAS*1(IX,KX))
         Q(IX,KX)=EMX*AX
        RETURN
         END
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```

SUBROUTINE GNURE (RH, G, P, T, R,	X, X1, CF	F,ST,L)	
COMMON/CP/CPI,GI ,RGAS			
COMMUN/HOT/AH(3), bH(3), CH(3), XSTR,	REC,	RT, SH, IT, IVIS	
HDEL=R-0+9/2.			
HAW=1.+REC*3*0/2./HDEL			
IF(IT .EQ.0) 1 = AH(L) * (X-X1) * + 2+BH(	L) * ( x = x 1 )	+CH(L)	
IF (IT .EQ.1) GU TO 46			
Hw=CPI*I*			
HW=HA/HDEL			
GO TO 48			
46 HW=HAW			
48 A=HAN-1.			
B=HN-1.			
C=SQRT((A+B)**2+4.*A)			
FC=A/(ASIM((A-A)/C)+ASIM((A+B)/C))			
FRX=HAM**(.7/2)/(FC*(HK)**(1.474))	<u> </u>		
CALL VIS(T, XM NU)			
REX=RH*Q*(X+XSTR)*RT /XMMU			
REXI=FRX*REX			
CFI=.088*(ALUG10(RFX1)-2.3686)/(AL	OG10(REXI	)-1.5)**3	
CF=CF1/FC			
ST=CF*SH/2.			
REIJRN			
END			
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			•
		•	
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1.

SUBROUTINE VIS(1,XMUU) XMUU=2.2/*T**1.5*1.E-0 RETURN END			
		Angeles (1984)	
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AND THE RESIDENCE OF THE PROPERTY OF THE PROPE			
		, A Parallel	<u> </u>
			فسند وسيميون والمشافر ووسيها والمؤولة المستعمل والموارقة
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			والمراكز والمراكز فالمستحولا المستحولا والمستحدث والمراكز والمستحدث والمراكز والمستحدث والمستحدث والمستحد

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SUBROUTINE SWARF (X1, Y1, Z1, X2, Y2, Z2, X3, Y3, Z3, X4, Y4, Z4, AVX, AVY, AVZ,
   IXNX, XNY, XNZ, AS, XO, YO, ZO, LH)
    DIMENSION XPA(4), YPA(4), ZPA(4), XI(4), ETA(4)
    XPA(1)=X1
    YPA(1)=Y1
    ZPA(1)=21
    ZPA(2)=Z2
    SY=(S)A9Y
    XPA(2)=X2
    XPA(3)=X3
    YPA(3)=Y3
    ZPA(3)=23
    ZPA(4)=Z4
    YPA(4)#Y4
    XPA(4)=x4
    T1X=X3-X1
     T1Y=Y3-Y1
     T12=23-21
     T2x=x4-x2
     154=44-45
     T2Z=Z4-Z2
     XNX=12Y*T1Z-11Y*T2Z
     XNY=11X+12Z-12x+11Z
     XNZ=T2X*T1YmT1X*T2Y
     VN=SQRT(XNX**2+XNY**2+XNZ**2)
     IF(VN.LE.1.E-13)GO TO 6
     XNX=XNX/VN
     XNY=XNY/VN
     XMZ=XMZ/VM
     D=XNX*(AVX-X1)+XNY*(AVY-Y1)+XNZ*(AVZ-Z1)
     PD=ABS(D)
     T=SQRT(T1X*T1X+T1Y*T1Y+T1Z*T1Z)
     11X=11X/T
     T1Y=T1Y/T
     T12=112/T
     12X=XNY*T1Z-XNZ*T1Y
     12Y=X1/2*11X-X1X*T1Z
     T2Z=XNX*T1Y=XNY*T1X
     DU 1000 J=1,4
     XPA(J) = XPA(J) + X \lor X * D
     YPA(J) = YPA(J) + XNY*D
     ZPA(J) = ZPA(J) + \times NZ * D
     U==0
     XDIF=XPA(J)=AVX
     YDIF=YPA(J)-AVY
     ZDIF=ZPA(J)-AVZ
     XI(J)=T1X*XDIF+T1Y*YDIF+T1Z*ZDIF
1000 ETA(J)=T2X*XD1F+T2Y*YD1F+12Z*Z01F
     XIO=(XI(4)*(LIA(1)=ETA(2))+XI(2)*(ETA(4)-ETA(1)))/(ETA(2)-LIA(4))
    1/3.
     ETAU=-ETA(1)/3.
     DU 1020 J=1,4
     VIx = (L)Ix = (L)IX
1020 ETA(J)=ETA(J)=ETAO
     XU=AVX+T1X+XIO+12X+ETAO
     OAT3*YST+UIX*YIT+YVA=OY
     ZU=AVZ+T1Z*X10+12Z*ETAO
     AS=(ETA(2)+ETA(4)) *(XI(3)-XI(1))/2.
```

```
RETURN
 END
 SUBROUTIVE LTH*(X1, Y1, Z1, X2, Y2, Z2, X3, Y3, Z3, X4, Y4, Z4, P1, P2, P3, P4;
191,92,93,94,71,72,73,74,7H1,7H2,7H3,7H4,XK<u>1,XK2,XK3,XK4,AVG,</u>
2XXTHX, XYLFI, XX *UM, CF -, SI, LH)
 COMMON/P/PINE, PTOT, TTOT
 CUMMON/CP/CPI,GI
                   RGAS
 COMMON/SHF/XSHFT,YSHFT
                                       REC.
                                                  RT, SH, II, IVIS
 COMMON/HOT/AH(3), BH(3), CH(3), XSTR,
 COMMON/VISE/XVIHX,YVLFT,XVMOM
 P=XK1*P1+XK2*P2+XK3*P3+XK4*P4
 Q=XK1*Q1+X<2*Q2+XK3*G3+XK4*Q4
 T=XK1*T1+X42*T2+XK3*T3+XK4*T4
 TH=XK1*TH1+XK2*TH2+XK3*TH3+XK4 ; H4
 RH=P/KGAS/T
 R=CPI*T+Q*0/2.
 AVX=XK1 *X1+XK2*X2+XK3*X3+XK4*X4
 AVY=XK1*Y1+XK2*Y2+XK3*Y3+XK4*Y4
 AVZ=XK1*Z1+XK2*Z2+XK3*Z3+XK4*Z4
 CALL SNARF(X1,Y1,Z1,X2,Y2,Z2,X3,Y3,Z3,X4,Y4,Z4,AVX,AVY,AVZ,XNX,
1XNY, XNZ, ASS, XU, YO, ZO, LH)
 CFF=0.
 XBP=0.
 IF(IVIS.EQ.1)CALL GNURE(RH,Q,P,T,R,
                                              XO, XBP, CFF, ST, 1 )
 RHQ=RH*Q*Q/2.
 PAV=P=PINF
 DXTHX=-PAV*XNX*ASS
 DYLFT= PAV*XNY*ASS
 XNZZEI
 IF (LH.EQ.3) XNZZ=XNZ
                       *C(IS(TH)*ASS*RHQ
 DXTHXV=-CFF
 DYLFTV=CFF
                 *SIN(TH) *ASS*RHQ
 DXTHXV=DXTHXV*AVG
 DYLFTV=DYLFTV*AVG
 XMS=XU-XSHFT
 YMS=YU-YSHFT
 DMUMV=YMS* )XIHXV+XMS*DYLFIV
 VXHTXG+XHTVX=XHTVX
 YVEFT=YVEFT+UYEFTV
 VMCMG+MOMVX#MOMVX
 DXTHX=DXTHX*AVG+DXTHXV
 DYLFT=DYLFT*AVG+DYLFTV
 DMOM≒YMS⊁DXTHX+XMS¥DYUFT
 XXTHX=XXTHX+DXTHX
 XYLFT=XYLFT+DYLFT
 MCMC+MOMXX#MOMXX
 RETURN
 END
```

AS=0.

```
SUBROUTINE CAT
   COMMON/IN/PI, TI, NI, THI, EMI, GAMI, ZI
   COMMUNICATE/TTE, PIC, NC, GC, PC, THE, XNUC, ZC, EMC
   COMMON/P/PINF, PTOT, ITOT
   COMMUNICAICHIGI , KGAS
   CUMMON/X/X(2,50),Y(2,50),Z(2,50),TH(2,50),XNU(2,50),
  1P(2,50),T(2,50),EM(2,50),XMU(2,50),U(2,50)
   A=1. $ B=0.
   TUTS=TIOT & POTS=PTOT & GIS=GI &ZIS=ZISEMIS=EMI
   11=1
   RB = XNU(1,2) + TH(1,2)
   TH(2,1)=TH(1,1)
20 SLA=A*TAN(TH(2,1))+B*TAN(TH(1,1))
   SLB = IH(1,2) - xHU(1,2)
   SLB=A*TAN(SLB)
   1F(B.GT.O.)SLH=SLB+B*TAN(TH(2,1)=XMU(2,1))
   CALL GEM(X(1,2),Y(1,2),SLB,X(1,1),Y(1,1),SLA,X(2,1),Y(2,1))
   Z(2,1) = GETZ(X(2,1))
   XNU(2,1)=R8-TH(2,1)
   CALL PM(2,1)
   TIDI=TIC & PIOT=PIC & G1=GC &Z1=ZC SEMI=EMC
   RC=XNUC-THC
   TH(2,2)=TH(2,1)
   XNU(2,2)=RC+TH(2,2)
   X(2,2)=x(2,1)
   Y(2,2)=Y(2,1)
   Z(2,2) = GETZ(x(2,2))
   CALL PM(2,2)
   ER3=(P(2,1)=P(2,2))/PC
   IF(ABS(ER3).LT.1.E-04)GU TO 16
   CALL ERROR (IER, IT, TH(2,1), ER3,1,01, TH23, ER23)
   TIUT=TOTS & PIUT=POTS & GI=GIS &ZI=ZIS SEMI=EMIS
   GU TU 20
16 CHNTINUE
   TTOT=TOTS & PTOT=POTS & GI=GIS &ZI=ZIS &EMI=EMIS
   IF (B.GT.O.) RETURN
   17=1
   A=.5 $ B=.5
   GD 10 20
   END
```

```
SUBROUTINE COML (DAUE)
  COMMON/X/X(2,50),Y(2,50),Z(2,50),TH(2,50),XNU(2,50),
 1P(2,50), (2,50), EM(2,50), XMU(2,50), Q(2,50)
  COMMON/CML/XCS, YCS
  COMMON/P/PINE, PIOT, TIOT
  COMMON/F/PF, TF, WF, THF, EMF, GF
  COMMUNICATORIGE
                    , KGAS
  COMMON/CNTC/TTG, PTC, NC, GC, PC, THC, XNUC, ZC, EMC
  PCC=(PF+P(1,1))/2.
  GM1=GF-1.
   GP1=GF+1.
   EMF 2=EMF *E MF
   DUM=1.+GM1 x EMF 2/2.
   PTF=PF*DUM**(GF/GM1)
   TTF=1F*OUM
   TOTS=TTOT $PO(S=PTOT $GIS=GI
   XMUF=ASIN(1./LMF)
   [T=1
   BET=(THF-XMUF+TH(1,1)) *1.1-1HF
20 DUM=(EMF*SIN(BET))**2
   PC=(2.*GF*)UM-GM1)/GP1
   TC=PC*(GM1*DUM+2.)/DUM/GP1
  EMC=(EMF2*(GP1*PC+GM1)-2.*(PC*PC-1.))/(GM1*PC+GP1)/PC
   EMC=SORT(EMC)
   PC=PC*PF
   THC=TAN(BET) * (GP1*EMF2/(DUM-1.)/2.-1.)
   THC=ATAB([ /THC) +THF
   PTC=(2.*TC/(GM1*EMF2+2.))**(GF/GM1)
   PTC=PC/PTC
   TTC=TIF
   TC=TC*TF
   RA=XNU(1,1)+TH(1,1)
   Z(2,1)=GETZ(xC2)
   XMU(2,1)=RA-TH(2,1)
   CALL PM(2,1)
   ER4=(PC-P(2,1))/PCC
   IF(ABS(ER4).LT.1.E-04)GO TO 16
   CALL ERROR (4, IT, BET, ER4, 1.05, BETT, ER41)
   GO TO 20
16 DNUE=ABS(XVU(2,1)-XNU(1,1))
   TTOT=TOTS &PTOT=POTS &GI=GIS
                                              ORIGINAL PAGE IS
   wC=wF
                                             OF POOR QUALITY
   GÇ≓GF
   ZC=Z(2,1)
   XNUC=0.
   RETURN
   END
```

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50. 3.09	418.8	28.97	0.	10.	1 • 4 5 •	6.	10.
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APPENDIX III
LISTING OF EQUILIBRIUM FLOW PROGRAM

```
PROGRAM NOZUE(IMPUT, OUTPUT, TAPES=IMPUT, TAPE6=6UTPUT)
    COMMON/IN/PI, II, NI, THI, EMI, GI, ZI, HI, RHI, UI
    COMMON/SHF/XSHFT, YSHFT
    COMMON/ [HRMAX/THRMAX
    COMMON/X/X(2,50),Y(2,50),Z(2,50),TH(2,50),XNU(2,50),
   1P(2,50),T(2,50),EM(2,50),XMU(2,50),Q(2,50),H(2,50),KH(2,50),
   2G(2,50)
    COMMON/D/PHI1
    COMMON/HOT/AH(3), BH(3), CH(3), XSTR,
                                            REC.
                                                       RT, SH, IT, IVIS
    COMMON/C/DNUV, DNUC, XC1, YC1, XV1, YV1, DNUL
    COWMON/CML/XCS, YCS
    COMMON/P/PINE, PTOT, TTOT
    COMMON/D3/ AZ,8Z,CZ
    COMMON/V/AV, BV, CV, XV, XV2, YV2
    COMMON/VISF/XVTHX, YVLF1, XVMOM
    COMMON/CP/CPI,
                         RGAS
    COMMON/FRIC/CF(50),ST(50)
    COMMON/F/PF, TF, NF, THF, EMF, GF
    COMMON/CNTC/TTC, PTC, WC, GC, PC, THC, XNUC, ZC, EMC
    DIMENSION HOL(11), HOLE(6), DNUE(10)
    DATA HOLE/2HEO, 2HE1, 2HE2, 2HE3, 2HE4, 2HE5/
    DATA HOL/2HV1,2HC1,2HA ,2HB ,2HC ,2HD ,2HV3,2HC3,2HF ,2HC4/
97 FORMAT(15,8E12.4)
98 FORMAT(/)
10 FORMAT (8E10.0)
    D=0.
    EPS=1.E-05
    DO 23 L=1,3
    AH(L)=0.
    BH(L)≅().
#23 CH(L)=0.
    READ(5,100) PI, II, WI, THI, EMI, PINF
    READ(5,100)PF, TF, WF, THF, EMF, GF
    READ(5,100) XVI, YVI, XV2, XC1, YC1, XC2, CYV, DNUC
    READ(5,100)XF1
    READ(5,100)XTHX,YLFT,XMOM,XVTHX,YVLFT,XVMOM,XSHF1,YSHFT
    READ(5,5921) ICF, DXC, JTF, DTH, IVIS, IT
    IF (IVIS, ED. I) READ (5, 100) XSTR, PEC.
    IF(IVIS, 50.1. AND. IT. EQ. 0) READ(5, 100) AH(1), BH(1), CH(1)
21 FORMAT(15,E10.0,15,E10.0,315)
    HI=FH(PI,WI,T1)
    PHII=NI
    GI=FGAM(TI,PI,NI)
    RHI=RHE@(HI,PI,WI,DUM)
    AI=SQRT(GI*PI/RHI)
    UI=E MI*AI
    XHXI = XIHX
    YLFTI=YLFT
    MOMI = X MOMX
    XVIHXI=XVIHX
    YVLFTI=YVLFT
    MCHVX=IMOMVX
    DNUC=DNUC/57.3
    THI=THI/57.3
    DTH=DTH/57.3
    READ(5,100) AZ, BZ, CZ
    ZC1=GETZ(XC1)
    ZV1=GETZ(XVI)
    ZC2=GETZ(XC2)
    7.T=7.V.1
```

```
5455 FORMAT (1417/1/1)
      WRITE (6, 1020)
1020 FORMATO
                  14X * E G U I L I B R I U M
                                                FLOW
                                                          NOZZLE
     1 S I G N*)
      WRITE(6,400) PI, THI, EMI, TI, GI, WI, PINF
 400 FORMATE ///JUX, *INITIAL PROFILE*//3X*PRESSURE*7X*THETA*8X*MACH*
     16X*TEMPERATURE*5X*GAMMA*7X*PHI*8X*PINF*/7E13.5)
      WRITE(6,5930) XV1, YV1, XV2, XC1, YC1, XC2, DYV
5930 FORMAT(///5x*xv1*10x*YV1*10x*xV2*10x*xC1*10x*YC1*10x*XC2*10X*DYV*/
     17E13.5///)
1800 FORMAT(*
                THRUST= *E13.5,7X*LIFT = *E13.5,7X*MOMENT= *E13.5)
      WRITE(6,1800)XTHX, YLFT, XMOM
1900 FORMAT (* VISCOUS THRUST= *E13.5,7X*VISCOUS LIFT= *E13.5,7X*
     1VISCOUS MOMENT= *E13.5)
      WRITE(6,1900)XVTHX, YVLFT, XVMOM
      WRITE(6,5923)XSHFT, YSHFT
5923 FORMAT (9X * MOMENT AXIS * / 12X * X = * £ 13.5 / 12X * Y = * £ 13.5 / / /)
      WRITE(6,1001) AZ,8Z,CZ
1001 FORMAT (9x*LATERAL EXPANSION EQUATION*/9x,22HZ(x) = AZ*X**2+BZ*X+CZ
    .1/12X*AZ =*E13.5/12X*BZ =*E13.5/12X*CZ =*E13.5)
      RG=49800.
      RGAS=RG/WF
      CPI=G
             F*RGAS/(G F=1.)
      XC55=XC5
      THC1=THI-DNUC
      DO 5000 IXC=1, ICF
     XC2=XC22+FLOAT(IXC+1)*DXC
      YG2=YC1+TAV(THC1)*(XC2-XC1)
      YV2=YC2+DYV
     IHT-((IVX-SVX)/(IVY-SVY)) NATA=VUND
     CALL THM(RHI, UI, PI, HI, TI, EMI, GI, PINF, YV1, YC1, DYV, XV2, THRMAX, DNUV,
     1DNUC, XC2)
     WRITE (6,6364) THRMAX
6364 FORMAT(1H131X*IDEAL THRUST =*E12.4)
     YCZ=YC1+TAN(THC1)*(XC2-XC1)
     YVZ=YCZ+DYV
     THC=ATAN((YC2-YC1)/(XC2-XC1))
     DO 6000 JT=1,JTF
     XTHX=XTHXI
     YLFT=YLFTI
     IMOM=XMOMI
     XVTHX=XVTHXI
     YVLFT=YVLFTI
     IMOMPX MOMI
     KSTP=50
     ISTP=50
     IEND=0
     IEXT=0
     IFLG=0
     IND=0
     THX=1.E+10
     THJT=FLOAT(JT=1)*DTH
     TUHT+IHT-((1VX-SVX))(1VY-SVY)) MATA=VUND
     WRITE(6,1894)DNUV
1894 FORMAT(* VEHICLE EXPANSION = *E13.5)
     XV=XV1
     AV=YV1
     BV=TAN(THI+DNUV)
     CV=0.
     YF1=AV+BV*(XF1-XV)
     IDUM=DNUV*57.3
     IF (IDUM.GT.11) IDUM=11
     IF (IDUM. EQ. 0) IDUM=1
     DELNU=DNUV/FLOAT(IDUM)
     IDUM=IDUM+1
     TMAY=IDHM
```

```
DU 10 I=1, IMAX
     X(1,I)=XV1
     Y(1,I)=YV1
     Z(1, I) = GETZ(XV1)
     TH(1, I)=THI+FLCAT(I-1)*DELNU
     M = I - I
     XNU(1,I)=FLOAT(I=1)*DELNU
     IF(I.NE.1)GO TO 8
     P(1,I) = PIST(1,I) = TISH(1,I) = HISEM(1,I) = EMISG(1,I) = GISO(1,I) = UIS
    1RH(1,1)=RHI
     GD TD 9
   8 CALL PM(DELNU,P(1,1),T(1,1),H(1,1),EM(1,1),G(1,1),U(1,1),RH(1,1),
    1P(1,M),T(1,M),H(1,M),EM(1,M),G(1,M),Q(1,M),RH(1,4))
   9 XMU(1, I) = ASIN(1,/EM(1, I))
  10 CONTINUE
     IDUM=DNUC*57.3
     IF(IDUM.GT.11) IDUM=11
     IF(IDUM.EQ.O) IDUM=1
     DELNU=DWUC/FLOAT(IDUM)
     IDUM=IDUM+1
     X(2,1) = XC1
     Y(2,1)=YC1
     Z(2,1)=GETZ(XC1)
     ICWL=0
     I=1
     THII=IHI
4
     XNUI=∪.
 20 CONTINUE
     TH(2,1)=THII=FLOAT(I=1)*DELNU
     XNU(2,1)=FLUAT(1-1)*DELNU+XNU1
     IF(I.NE.1)GO TO 86
     P(2,1) = P151(2,1) = T15H(2,1) = H15EM(2,1) = EM15G(2,1) = G15G(2,1) = U15
    1RH(2,1)=RHI
    GU TU 19
  86 CALL PM(DELNU,P(2,1),T(2,1),H(2,1),EM(2,1),G(2,1),G(2,1),RH(2,1),
   IP(1,1),T(1,1),H(1,1),EM(1,1),G(1,1),G(1,1),RH(1,1))
19 XMU(2,1)=ASIN(1./EM(2,1))
  22 CONTINUE
     K=2
35 CONTINUE
     IF(K.LT.KMAX) GO TO 41
     IF (IEND.EN.1)GO 10 53
     CALL VWALL (IMAX, KMAX)
     MM=K=I
     L=K-1
     IF (ICWL.EQ.I) L=K
     IF(X(2,K).LT.XV2=EPS)GD TO 24
     TALL ENDD (L, MM, KMAX)
     X(5,K)=XVS
     IF (KSTP. GE. KMAX) KSTP=KMAX
     IND=1
     GU 10 17
  24 [F(I.GT.1) GO TO 30
     AV=Y(2,KMAX)
     BV=TAN(TH(2,KMAX))
     TV=(YV2-AV-BV*(XV2-X(2,KMAX)))/(XV2-X(2,KMAX))**2
     THV2=ATAN(BV+2.*CV*(XV2-X(2,KMAX)))
     XA=X(S)KAVX)
       IF(XF1.GT.XV)YF1=AV+BV*(XF1-XV)+CV*(XF1-XV)**2
     SLE=(YF(-YC2)/(XF(-XC2)
     IF(THV2.LT.0.) GO TO 462
     DO 16 KT=2 KHAX
     XK1=XK2=XK3=XK4=0.25
     M≐KT≟ſ
     J=KT-1
```

```
IF (KT.EQ.KMAX) J=KT=2
      IF(KT.EQ.2.OR.KT.EU.KMAX)N=J
      IF (KT.EQ.2.DR.KT.ED.KMAX)XK3=0.
      IF(KT.EQ.2.DR.KT.EQ.KMAY)XK1=XK2=XK4=.333333
      CALL LTHM(X(2, M); Y(2, M), Z(2, M), X(1, N), Y(1, N), Z(1, N), X(1, J),
    1Y(1,J),Z(1,J),X(2,K1),Y(2,KT),Z(2,KT),P(2,M),P(1,N),P(1,J),
    SP(2,KT),Q(2,M),Q(1,N),Q(1,J),G(2,KT),T(2,M),T(1,N),T(1,J),
    3T(2,KT),TH(2,M),TH(1,N),TH(1,J),TH(2,KT),XK1,XK2,XK3,XK4,1.,
    4XTHX, YLFT, XMOM, CF(M), ST(M), 3)
      IF (KT.EQ.KMAX)
    1CALL LTHM(X(1,J),Y(1,J),Z(1,J),X(1,J),Y(1,J),O.,X(2,KT),Y(2,KT),O.
    2,x(2,KT),Y(2,KT),Z(2,KT),P(1,J),P(1,J),P(2,KT),P(2,KT),Q(1,J),
    30(1,J),0(2,KT),0(2,KT),T(1,J),T(1,J),T(2,KT),T(2,KT),TH(1,J),
    4TH(1,J),TH(2,KT),TH(2,KT),.25,.25,.25,.25,1.,XTHX, YLFT, XMUM,
    5CFU,STU,1)
16 CUNTINUE
      GO TO 53
41 CONTINUE
      IF (ICWL.EQ.1.AND.K.EQ.2.AND.IEXT.EQ.0) CALL CWALL (INAX, KMAX,
    1KSTP, ISTP)
      IF (ICAL.EQ.1.AND.K.EQ.2.AND.IEXT.EQ.1) CALL CNT
      IF(ICWL.EQ.1)L=K+1
      IF(I.EQ.1) L = X-1
      LL=K+ICWL-1
      LM=L-1
                   .GT.ISTP.AND.IEND.EQ.1)GO TO 30
      IF(L
      MM = K = 1
      CALL FIX(2,K-1,1,L__,2,K)
      IF(I.EQ.1)60 TU 30
      IF(K_GT_1)SLA=(Y(2,K)-Y(2,MM))/(X(2,K)-X(2,MM))
      CALL GEM(X(2,MM),Y(2,MM),SLA,XC2,YC2,SLE,XC,YC)
      IF(xC.GE.x(2,K) .OR.XC.LT.X(2,MM)-EF5)GO TO 30
      KSTP=K
      WRITE(6,88)KSTP, ISTP, KNAX, IMAX
 88 FURMAT(1x,415)
 30 CONTINUE
      LM=L-1
      IF(I.EQ.1)G0 T033
       IF(IEXT.EQ,1)GU TO 32
       IF(ICHL.EQ.O.OR.K.GT.2)GO TO 32
      CALL LTHM(X(1,1),Y(1,1),Z(1,1),X(2,1),Y(2,1),Z(2,1),X(2,1),
    1Y(2,1),0.,×(1,1),Y(1,1),0.,P(1,1),P(2,1),P(2,1),P(1,1),Q(1,1),
2Q(2,1),Q(2,1),Q(1,1),T(1,1),T(2,1),T(2,1),T(1,1),TH(1,1),TH(2,1),
     31H(2,1),TH(1,1),.25,.25,.25,.25,1.,XTHX, YLFT, XMDM,CFL,STL,2)
      CALL LTHM(X(1,1),Y(1,1),Z(1,1),X(1,2),Y(1,2),Z(1,2),X(2,1),Y(2,1),
     1Z(2,1), X(2,1), Y(2,1), Z(2,1), P(1,1), F(1,2), P(2,1), P(2,1), Q(1,1), Z(1,2), Q(2,1), Z(2,1), Z(2,1), Z(1,2), Z(2,1), Z(2
     3TH(2,1),TH(2,1),.33333,.33333,.3333,0.,1.,XTHX, YLFT, XMOM,
     4CF(1),ST(1),3)
 32 CONTINUE
       XK1=XK2=XK3=XK4=.25
       IF (IEND. EQ. O. AND. K. EQ. KMAX) GO TO 17
       AVG=4.
       SLB=(Y(2,K)=Y(1,L))/(X(2,K)-X(1,L))
       CALL GEM(X(1,L),Y(1,L),SLB,XC2,YC2,SLE,XC,YC)
       RAT = (XC - X(1,L))/(X(2,K) - X(1,L))
       IF(RAT.G1.0.99)GD TO 144
       IF(RAT.GT.O.)GO TO 143
       AVG=2.
       GO TO 144
143 AVG=AVG-1.
144 CONTINUE
        IF((X(2, MM)-X(1, LM)), EG.O.)GOTO 148
```

```
RAT = (XC - X(1, LM))/(X(2, MM) + X(1, LM))
      IF(RAT.GT.0.99)GO TO 148
      IF (RAT.GT.O.)GO TO 145
      AVG=AVG-2.
      GO TO 146
  145 AVG=AVG-1.
  148 CUNTINUE
     AVG=AVG/4.
      CALL LTHM(x(2, MM), y(2, MM), Z(2, MM), x(1, LM), y(1, LM), Z(1, LM), x(1, L),
     1Y(1,L),Z(1,L),X(2,K),Y(2,K),Z(2,K),P(2,MM),P(1,LM),P(1,L),P(2,K),
     2Q(2,MM),Q(1,LM),Q(1,L),Q(2,K),T(2,NM),T(1,LM),T(1,L),T(2,K),
     STH(2, MM), TH(1,LM), TH(1,L), TH(2,K), XK1, XK2, XK3, XK4, AVG, XTHX, YLFT,
     4XMOM, CF(LL), ST(LL), 3)
      IF (IEND.EQ. 1.UR.K.LT.KMAX)GO TO 33
17 CUNTINUE
      M=K-1
      LIM
      IF (ICWL, EQ. 1) L=K
.
      AVG=3.
      SLA=(Y(2,K)-Y(2,M))/(X(2,K)-X(2,M))
5
      CALL GEM(x(2,M),Y(2,M),SLA,XC2,YC2,SLE,XC,YC)
      RAT=(XC-X(2,M))/(X(2,K)-X(2,M))
ថម
      IF (RAT.GT.0.99)GO TO 177
      AVG=AVG-1.
 图177 SLB=(Y(2,M)-Y(1,L))/(X(2,M)-X(1,L))
      CALL GEM(x(1,L), Y(1,L), SLB, XC2, YC2, SLE, XC, YC)
      RAT = (XC - X(1, L)) / (X(2, M) - X(1, L))
      IF (RAT. GT. 0.99) GU TO 178
      1F(RAT.GT.J.)GU TO 173
      AVG=AVG-2.
型173 AVG=AVG-1.
178 CUNTINUE
      AVG=AVG/3.
      CALL LTHM(X(2,M),Y(2,M),Z(2,M),X(1,L),Y(1,L),Z(1,L),X(2,K),Y(2,K),
     1Z(2,K),X(2,K),Y(2,K),Z(2,K),P(2,M),F(1,L),P(2,K),P(2,K),Q(2,M),
     20(1,L),N(2,K),Q(2,K),T(2,M),T(1,L),T(2,K),T(2,K),TH(2,M),TH(1,L),
     3TH(2,K),TH(2,K),.33333,.33333,.33333,0.,AVG,XTHX, YLFT, XMUM,
     4CF(LL),ST(LL),3)
   43 CALL LTHM(x(1,L),Y(1,L),Z(1,L),X(1,L),Y(1,L),O.,X(2,K),Y(2,K),
     10., x(2, k), Y(2, k), Z(2, k), P(1, L), P(1, L), P(2, k), P(2, k), G(1, L), G(1, L),
     20(2,K),U(2,K),T(1,L),T(1,L),T(2,K),T(2,K),TH(1,L),TH(1,L),TH(2,K),
     3TH(2,K),.25,.25,.25,.25,1.,XTHX, YLFT, XMOM,CFU,STU,1)
   33 IF (IEND_EQ. 1) KMAX=ISTP
      K=K+1
      IF(K.LE.KMAX)GO TO 36
   53 KP=KMAX
      IF (IEND.EQ. 1) KP=KMAX-1-1CWL
      IF (IND.EG.I) IEND=1
      IND=0
      WRITE (6,6885)
$385 FORMAT(1X*PT.*6X*X*11X*Y*8X*PRESSURE*5X*ANGLE*8X*MACH*4X*TEMPERATU
     TRE*1X*PM FJNCTION*3X*VELUCITY*)
      DO 50 L=1,KP
      WRITE(6,97) L,x(2,L),Y(2, L),P(2,L),TH(2,L),EN(2,L),T(2,L),XNU(2,
     1L),Q(2,L)
   50 CALL SWITCH(2, L, 1, L)
      WRITE(6,2001)CFU,STU,CFL,STL
2001 FURMAT(* VEH. FRIC. COEF= *E13.5,2x*VEH. STANTON NUM.= *E13.5,2x*

1COWL FRIC. COEF.= *E13.5,2x*COWL STANTON NUM.= *E13.5)
      WRITE (6,450)
      NPR1=IMAX/5
I
      DO 106 K=1, NPR1
      K1=K$K2=K1+NPR1&K3=K2+NPR1&K4=K3+NPP1&K5=K4+NPR1
      KDONE=K5
```

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201 CN7280
 166 CONTINUE
     IF (KDUNE . EQ. IMAX) GO TO 55
     NPR2=5*NPR1+1
     DU 414 K=NPR2, IMAX
     "RITE (6,550) CF (K), ST (K)
 414 CONTINUE
  55 CONTINUE
 450 FURMAT(1X,5(6X,*CF *,9X,* ST
 500 FORMAT (1x, 10E13.5)
 550 FORMAT (105x, 2E13.5)
     WRITE(6,98)
     WRITE (6, 1800) XTHX, YLFT, XMOM
     WRITE(6,1900)XVTHX,YVLFT,XVMDM
     IMAX=KMAX
     I=I+1
     IF (I.GT.IDUM) ICWL=1
     IF (ICWL . EQ. U) K MAX=KMAX+1
     IF (IEND. EQ. 1) ISTP=KSTP+ICWL
     IF (IEND.EJ.1.AND.KP.EQ.1)GO TO 6000
     IF (IEND.EQ.1.AND.IEXT.EQ.1)GO TO 6000
     IF(IEXT.EG.O.AND.X(1,1).GE.XC2-EPS)GD TO 5900
     IF(ICWL.EQ.1)GD TO 22
     GO TU 20
 462 CUNTINUE
     WRITE(6,992)
 992 FORMAT (*THV2.LT.0*)
     GO TO 6000
5900 CUNTINUE
     IF(P(1,1).LE.PF)GD TO 5396
     CALL CUWL (D VUE)
     IDUM=6
     I=2
     XNUI=XNU(1,1)
     THII=TH(1,1)
     ICWL=0
     KMAX=KMAX+1
     DELNU=DNUE/FLOAT(IDUM)
     IDUM=IDUM+1
     IEXT=1
     GO TO 20
5396 CONTINUE
6000 CUNTINUE
5000 CUNTINUE
     END
```

```
SUBROUTINE CHALL (IMAX, KMAX, KSTP, ISTP)
    COMMO%/X/X(2,50),Y(2,50),Z(2,50),TH(2,50),XMU(2,50),
   IP(2,50),T(2,50),EM(2,50),XMU(2,50),Q(2,50),H(2,50),RH(2,50),
   2G(2,50)
    COMMON/C/DYUY, DNUC, XC1, YC1, XV1, YV1, DNUL
    COMMON/CML/XCS, YCS
    D=0.
    IADD=0
    LUUP=0
    XTHM1=TH(1,1)=XMU(1,1)
    Q1=XNU(1,1)-TH(1,1)
    CALL INT(0.,x(1,2),Y(1,2),Z(1,2),TH(1,2),XNU(1,2),P(1,2),T(1,2),
   IH(1,2), EM(1,2), G(1,2), Q(1,2), RH(1,2), XMU(1,2),
   20,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
   2XA, YA, ZA, THA, XNUA, PA, TA, HA, EMA, GA, UA, RHA, XMUA, -1.)
    02 = XNU(1,2) = TH(1,2)
 44 XTHM2=THA-XMUA
    IF(LOOP.EQ.O)X[HM3=XTHM2
    SLA=(TAN(XTHM2)+TAU(XTHM3))/2.
    SLB=(YC2-YC1)/(xC2-xC1)
                           ,SLA,XC2,YC2,SLB,XC,YC)
    CALL GEM (XA
                   ·ΥA
    IF(XC.LE.XC2)GO TO 43
    TADD=1
    DX = X(1,2) = X(1,1)
    SLU=(Y(1,2)-Y(1,1))/DX
    I T=1
    XA = (X(1,2) + X(1,1))/2.
 24 RAT=(XA-X(1,1))/DX
    SLB=XTHM1+RAT*(XTHM2-XTHM1)
    SLB=TAN(SLB)
    IF(LOOP.EG.1)SLB=(SLB+TAN(XTHM3))/2.
    CALL GEM(X(1,1),Y(1,1),SLU,XC2,YC2,SLB,XAT,YA)
    EREADS ((XA-XAT)/UX)
     IF(ER.LT.1.E=04)GU TO 63
    IT=IT+1
     IF(IT.GT.10)GO TO 68
    XA=XAT
    GO TO 24
 68 WRITE(6,35)
患38 FORMAT(* TOO MANY ITER IN CWALL *)
    WRITE(6,39)LOOP, SLU, SLE, XA, XAT
 39 FURNAT(1X,15,5E13.5)
   STOP
 63 CUNTINUE
    CALL INT(RAT, X(1,1), Y(1,1), 7(1,1), Th(1,1), XMU(1,1), P(1,1), T(1,1),
    1H(1,1),EM(1,1),G(1,1),Q(1,1),RH(1,1),XMU(1,1),X(1,2),Y(1,2),
    2Z(1,2),TH(1,2),XNU(1,2),P(1,2),T(1,2),H(1,2),EM(1,2),G(1,2),
    3U(1,2),RH(1,2),XMU(1,2),XA,YA,ZA,THA,XNUA,PA,TA,HA,EMA,GA,UA,
   -4RHA,XMUA,-1.)
🏝 43 RA=THA+XNUA
     IF (ABS(xC2-XC).LE,.0001)xC=xC2
     X(2,1)=XC
     Y(2,1)=YC
     2(2,1)=GETZ(XC)
     TH(2,1)=TH(1,1)
     XNU(2,1)#RA-TH(2,1)
     CALL PM(DNU ,P(2,1),T(2,1),H(2,1),EM(2,1),G(2,1),Q(2,1),RH(2,1),
    1PA, TA, HA, EMA, GA, UA, RHA)
     RQ3D=RH(2,1)*N(2,1)/2(2,1)
     DNU3=DNŪ
```

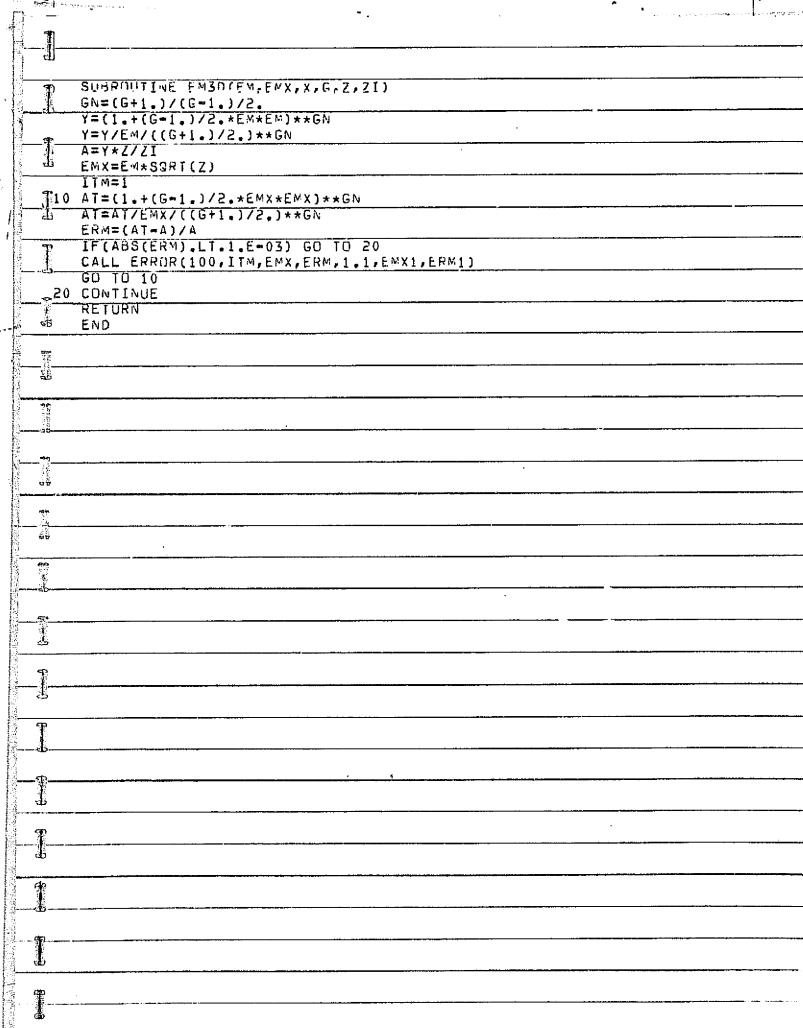
```
ERT=.001
10 CONTINUE
    CALL PM(DNU3,P(2,1), (2,1), H(2,1), EM(2,1), G(2,1), G(2,1), RH(2,1),
   1PA, TA, HA, EMA, GA, UA, RHA)
    RQT=RH(2,1) *0(2,1)
    ERQ=(RGT-RG3D)/RG3D
    IF(ITT.GE.10)ERT=.005
    IF (ABS(ERG) .LT .ERT) GO TO 20
    CALL ERRUR(1, ITT, UNU3, ERG, 1, 1, DNUZ1, ERGZ1)
    GO TO 10
 20 CONTINUE
    XMU(2,1)=ASIN(1./EM/2,1))
    XTHM3=[H(2,1) → XHU(2,1)
    IF(LOOP,EW.1)GO TO 6
    LOOP=1
    GU TO 44
  6 IF (IADD. EQ. 0) RETURN
    IMAX=IMAX+1
    KMAX=KMAX+1
    KSTP=KSTP+1
    ISTP=ISTP+1
    00 46 JJ=3, IMAX
    LJ=IMAX-JJ+3
    L1=LJ-1
 46 CALL SWITCH(1, L1, 1, LJ)
    WRITE(6,181)IADU, XA, X(1,1), X(1,2)
181 FORMA ( (1X, 15, 3E13.5)
   CALL INT(0., XA, YA, ZA, THA, XNUA, PA, TA, HA, EMA, GA, UA, RHA, XMUA, 10, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, X(1,2), Y(1,2), Z(1,2), TH(1,2), XNU(1,2),
   2P(1,2),T(1,2),H(1,2),EM(1,2),G(1,2),O(1,2),RH(1,2),XMU(1,2),=1,)
    RETURN
    END
```

```
Ŀ
    SUBROUTINE ENDO(L, KK, K6)
    COMMON/V/AV, BV, CV, XV, XV2, Y12
    CUMMUN/X/X(2,50),Y(2,50),Z(2,50),TH(2,50),XNU(2,50),
   1P(2,50),T(2,50),EM(2,50),XMU(2,50),Q(2,50),H(2,50),RH(2,50),
   2G(2,50)
    ITT=1
    B=0.
    A=1
    XM1=TH(1,L )+XMU(1,L )
    XM2=IH(5,KK)+XMU(5,KK)
    XM3=0.
    Q1=IH(1,L)+XNU(1,L)
    02=[H(2,KK)+XNU(2,KK)
    XA = (X(1,L) + X(2,KK))/2.
    Dx = x(2,KK) = x(1,L)
    SLM=(Y(2,KK)=Y(1,L_))/DX
12 RAT=(XA-X(1,L ))/DX
    SLP=xM1+RAT*(XM2=XM1)
    SLP=A*SLP+3*XN3
95
    CALL GEM(X(1,L ),Y(1,L ),SLM,XV2,YV2,SLP,XAT,YA)
    ER=ABS((XA-XAT) /DX)
    IF(ER.LT.1.E=03)GD TO 14
    111=111+1
    IF(ITT.LE.10)GO TO 8
    WRITE (5,33)
第33 FORMAT(* TOO MANY ITER IN END *)
    WRITE(6,34)L,KK,K6,XA,XAT,X(2,KK),X(1,L),SLP,XM3
 34 FORMAT(1x,315,6E13,5)
    SIDP
S XA=XAT
    60 TO 15
#14 WA=Q1+RAT*(WZ=Q1)
    CALL INT(RAT, X(1,L), Y(1,L), Z(1,L), 1H(1,L), XAU(1,L), P(1,L),
   1T(1,L),H(1,L),EM(1,L),G(1,L),Q(1,L),RH(1,L),XMU(1,L),X(2,KK),
   2Y(2,KK),Z(2,KK),TH(2,KK),XNU(2,KK),P(2,KK),T(2,KK),H(2,KK),
   5EM(2,KK),G(2,KK),Q(2,KK),RH(2,KK),XMU(2,KK),XA,YA,ZA,THA,XNUA,
   4PA, TA, HA, EMA, GA, UA, RHA, XMUA, 1.)
    RA=XNUA-THA
    X(2,K6)=XV2
    Y(5,K6)=YV2
    Z(Z,K6)#GETZ(XVZ)
    TH(2,K6)=ATAN (BV+2.*CV*(XV2-XV))
    XNU(2,K6) = RA+TH(2,K6)
    DMD = XMD(5.49) = XMDA
    CALL PM(DNJ ,P(2,K6),T(2,K6),H(2,K6),EM(2,K6),G(2,K6),Q(2,K6),
   1RH(2,K6),PA,TA,HA,EMA,GA,UA,RHA)
    R03D=RH(2,K6)/J(2,K6)/Z(2,K6)
    DNU3≃DNU
    TT=1
    ERT=.001
 TO CONTINUE
    CALL PM(DNU3,P(2,K6),T(2,K6),H(2,K6),EV(2,K6),G(2,K6),Q(2,K6),
   IRH(2,K6),P4,TA,H4,EMA,GA,UA,RHA)
    RQT = RH(2, K6) * Q(2, K6)
    ERG=(RGT-RJ3D)/RD3D
    IF(IT.GE.10)ERT=.005
     IF (ABS(ERJ), LT. ERT) GU TU 16
    CALL ERROR(2, IT, DNU3, ERQ, 1.1, DNUZ1, ERGZ1)
    GO YO 10
16 XMU(2,K6)=ASIN(1,/EM(2,K6))
    TEND=1
    iF(B.Gf.O.)RETURN
```

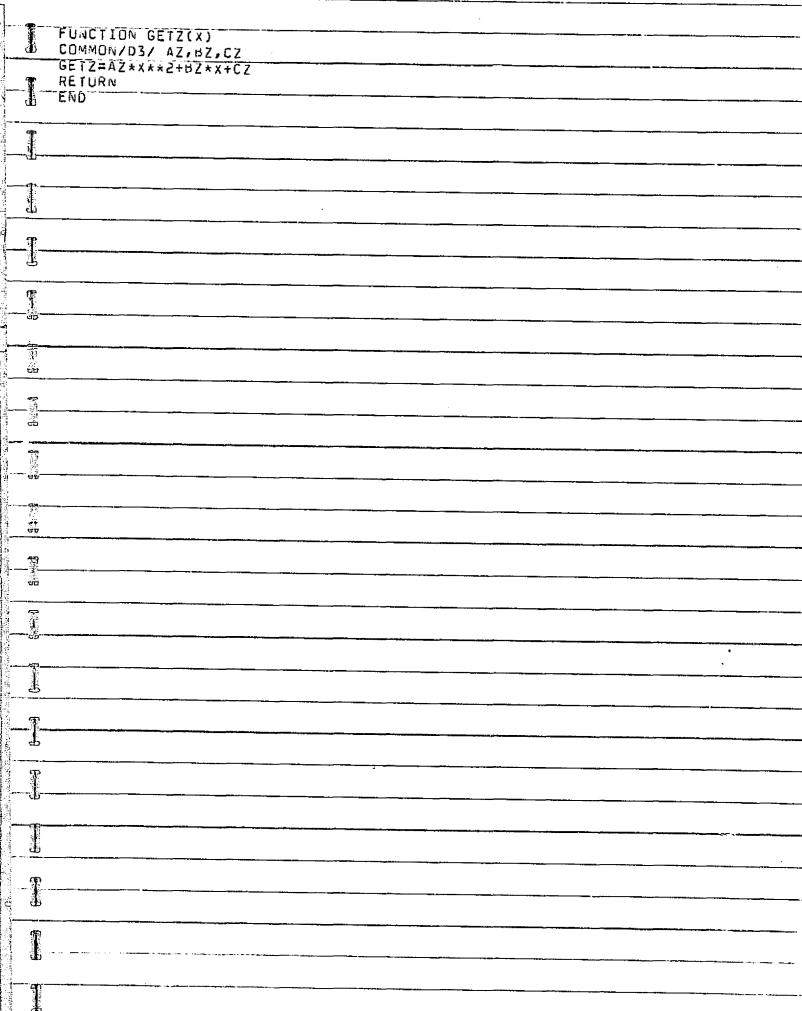
	07,5
2 d	A=.5 XM3=TH(2.K6)+XMU(2.K6)
	XM3=TH(2,K6)+XMU(2,K6) GO TO 12
	END
, A	
•	
1	
-	
4 1	
1	
	· · · · · · · · · · · · · · · · · · ·

1 SUBROUTINE INT(RAT, X1, Y1, Z1, TH1, ANU1, P1, T1, H1, EM1, G1, U1, RH1, XMU1, 1x2, y2, z2, 142, x vu2, P2, T2, H2, EH2, G2, U2, FH2, XMU2, x3, y3, Z3, 1H3, 2XNU3, P3, T3, H3, EH3, G3, U3, RH3, XMU3, OPT) HT1=H1+U1\*U1/2. H15=H2+U2\*J2/2. Q1=XNU1+3P[\*TH1 SHT\*T9C+SUMX=SØ X3=X1+RAT\*(X2-X1)Y3=Y1+RA1\*(Y2-Y1) Q3 = Q1 + RAT \* (Q2 - Q1)P3=P1+RAT\*(P2-P1) T3=T1+RAT\*(T2-T1) XNU3=XNU1+RAI\*(XNU2-XNU1) TH3=(Q3-XHU3)/OPT HI3=HI1+RAT\*(HI2-HI1) Ţ, U3=U1+RAT\*(U2-U1) G3=G1+RAT\*(G2-G1) H3=H1+RAT\*(H2=H1) RH3=RH1\*(P3/P1)\*\*(1./G3) EM3=U3/SQRT(G3\*P3/RH3) XMU3=ASIN(1./EM3) 23=GETZ(X3) ## ## ## RETURN END

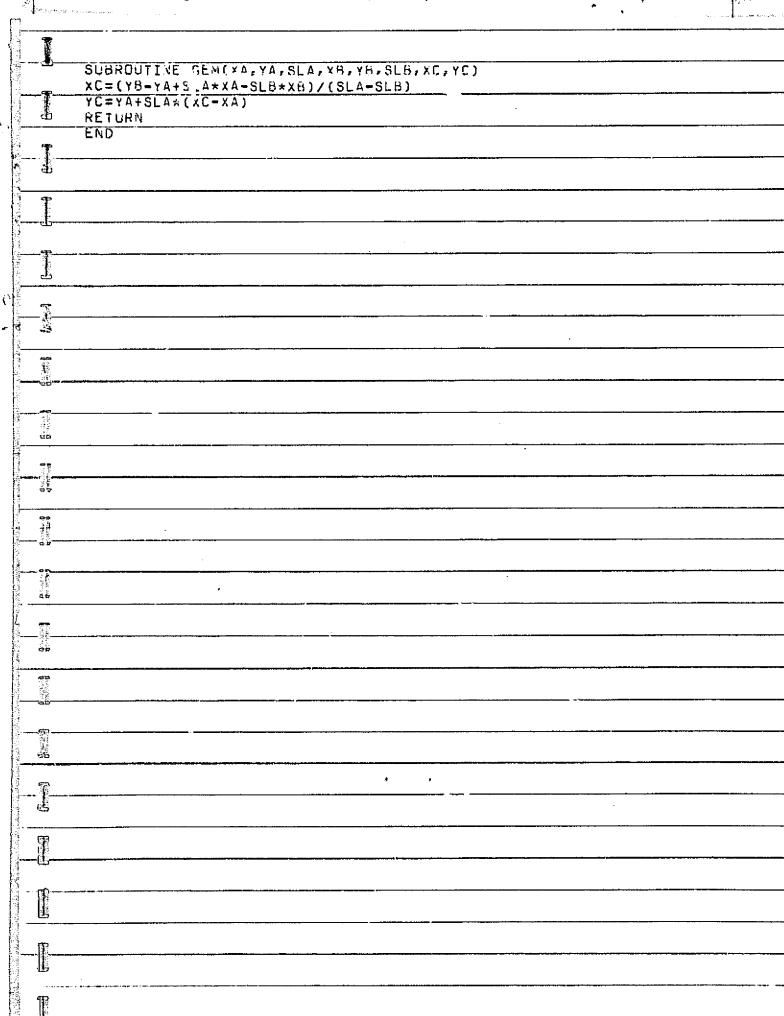
```
SUBROUTINE THM(RHI, UI, PI, HI, TI, EMI, GI, PINF, YV1, YC1, DYV, XV2, THRMAY,
  10NUV, UNUC, XC2)
  COMMON/D3/AZ, HZ, CZ
   A1=YV1-YC1
  F1=RHI*UI*A1
  Z2=AZ*XV2*XV2+BZ*XV2+C7
  Z5=AZ*XC2*XC2+dZ*XC2+CZ
   A2=(Z2+Z5)/2.*DYV
   IT=1
   DNU=(DNUV+DNUC) *SQRT((ZZ+Z5)/2.)
10 CALL PM(DNU,P2,T2,H2,EM2,G2,U2,RH2,PI,TI,HI,EMI,GI,UI,RHI)
  F2=RH2*U2*42
  ERT=(F2-F1)/F1
   IF (ABS(ERT) .LT.1, E=04) GO T() 20
   CALL ERROR(99, II, DNU, ERT, .9, DNU1, ERT1)
   GO TO 10
20 TH1=(PI=PI\F+RHI*UI*UI)*A1
   TH2 = (P2 - PIVF + RH2 * U2 * U2) * A2
   THRMAX=TH2=TH1
   RETURN
   END
```



```
SUBROUTINE SWITCH(12, K, 11, L)
COMMON/X/X(2,50).Y(2,50).Z(2,50),TH(2,50).XAU(2,50).
1P(2,50),T(2,50),EM(2,50),XMU(2,50),U(2,50),H(2,50),RH(2,50),
26(2,50)
              (I2,K)
X (I1,L)=X
    (I1,L)=Y
              (15,K)
   (I1,L)=Z
 Z
              (12,K)
 TH (I1,L)=TH (I2,K)
XNU(II,L)=XNU(I2,K)
   (I1,L)=P
             (I2,K)
 T
    (I1,L)=1 (I2,K)
H(I1,L)=H(I2,K)
G(I1,L)=G(I2,K)
RH(I1,L)=RH(I2,K)
EM (I1,L)=EM (I2,K)
XMU(I1,L)=XMU(I2,K)
 U(I1,L)=U(I2,K)
 RETURN
 END
```



```
SUBROUTINE VWALL (IMAX, KMAX)
  COMM(N) \times X \times (2,50), Y(2,50), Z(2,50), Th(2,50), XNU(2,50),
  1P(2,50),[(2,50),EM(2,50),xMU(2,50),Q(2,50),H(2,50),RH(2,50),
 2G(2,50)
  COMMON/V/AV, BV, CV, XV, XV2, YV2
  COMMON/C/DNUV, DNUC, XC1, YC1, XV1, YV1, DNUL
  IBEG=0
  ITw=1
  SL2=TH(1, IMAX)
  SL1=TAN(TH(2,KMAX=1)+XMU(2,KMAX=1))
  SL13=SL1
  CALL GEM(X(2,KMAX-1),Y(2,KMAX-1),SL1,X(1,IMAX),Y(1,IMAX),SL2,
  1XG, YG)
12 YW=AV+BV*(XG-XV)+CV*(XG-XV)**2
  ERW=(YW-YG)/(YV1-YC1)
  IF (ABS(ER#) LT.1_E-02) GO TO 10
  CALL ERROR(3, ITM, XG, ERM, , 9, XG1, ERW1)
  YG=Y(2,KMAX=1)+SL13*(XG-X(2,KMAX=1))
10 TH(2,KMAX)=ATAN(BV+2,*CV*(XG-XV))
  XNU(2, KMAX)=TH(2, KMAX)-TH(2, KMAX+1)+XNU(2, KMAX+1)
  X(2,KMAX)=XG
   Y(2,KMAX)=YG
  Z(2,KMAX)=GETZ(XG)
  K=KMAX
  M=KMAX=1
   DMD=XMD(5'K)+XMD(5'W)
  CALL PM(DNJ ,P(2,K),T(2,K),H(2,K),EM(2,K),G(2,K),Q(2,K),RH(2,K),
  1P(2,M),T(2,M),H(2,M),EM(2,M),G(2,M),U(2,M),RH(2,M))
   RQ3D=RH(2,K)*Q(2,K)/Z(2,K)
   DNU3=DNU
   IT=1
   ERT=.001
15 CONTINUE
   CALL PM(DNJ3,P(2,K),T(2,K),H(2,K),EM(2,K),G(2,K),Q(2,K),RH(2,K),
  1P(2,M),T(2,M),H(2,M),EM(2,M),G(2,M),Q(2,M),RH(2,M))
   RQT=RH(2,K)*u(2,K)
  ERG=(RUT-R330)/R33D
   IF(IT.GE.10)ERT=.005
  TF (ABS(ERQ).LT.ERT)GU TO 16
   CALL ERROR (4, IT, DNU3, ERQ, 1.1, DNUZ1, ERQZ1)
   GO TO 15
16 CONTINUE
   XMU(2,K)=ASIN(1./EM(2,k))
   IF (IBEG.EG.1) RETURN
   IBEG=1
   SL13=.5*(SL1+TAN(TH(2,KMAX)+XMU(2,KMAX)))
   GO TO 12
   END
```



SUBROUTINE ERROR (I, IT, x, ER, F, x1, ER1)	
IT=IT+1 IF(IT.LT.15) GO TO 12	
NRITE(6,13) 13 FORMAT(*ERROR TEST NUMBER *)	
WRITE (6,20) I	
20 FORMAT(I5) STOP	
12 IF(I1.GT.2) GO TO 14 ER1=ER	
x1=x	
X=X*F IF(X,EQ,X1) X=X+,02	_
RETURN 14 XD=X1=ER1*(X=X1)/(ER=ER1)	
ER1=ER	
X1=X X=XD	
RETURN END	,
	<del></del> -
	<del></del> ,
	—

----

```
SUBRUUTINE FIX(11, K1, 12, K2, 13, K3)
    COMMON/X/x(2,50),Y(2,50),Z(2,50),TH(2,50),XMU(2,50),
   1P(2,50), I(2,50), EM(2,50), XMU(2,50), G(2,50), H(2,50), RH(2,50),
   26(2,50)
    DUM3=0.
    9UM4=0.
    A=1.
    B=0.
    DUM1=TAN(TH(I1,K1) + XMU(I1,K1))
    DUM2=TAN(In(I2,K2)=xMU(I2,K2))
    XNU(13,K3) = .5*(XNU(11,K1) + XNU(12,K2) + TH(12,K2) - TH(11,K1))
    TH(I3,K3)=.5*(XNU(I2,K2)=XNU(I1,K1)+IH(I2,K2)+IH(I1,K1))
10 IF (8.GT.O.) DUM3=TAN(TH(13,K3)+XMU(13,K3))
    IF(B.G1.0.) DUM4=IAN(TH(I3,K3)=XMU(I3,K3))
    SL1=A*DUM1+B*DUM3
7
    SL2=A*DU%2+B*DU%4
    CALL GEM(X(I1,K1),Y(I1,K1),SL1,X(I2,K2),Y(I2,K2),SL2,X(I3,K3),
    1Y(13,K3))
    Z(13,K3)=GETZ(x(13,K3))
    DNU=XAU(I3,K3)=XAU(I1,K1)
    CALL PM(DNJ ,P(13,K3),T(13,K3),H(13,K3),EM(13,K3),G(13,K3),
    1Q(13,K3),R¬(13,K3),P(11,K1),T(11,K1),H(11,K1),EM(11,K1),
   2G(I1,K1), J(I1,K1), RH(I1,K1))
пb
    RQ3D=RH(I3,K3)*Q(I3,K3)/7(I3,K3)
    ERT = .001
    DNU3=UNU
    TTEI
 12 COMTINUE
    CALL PM(DNUS,P(13,K3),T(13,K3),H(13,K3),EM(13,K3),G(13,K3),
    1Q(I3,K3),RH(I3,K3),P(I1,K1),T(I1,K1),H(I1,K1),EM(I1,K1),
   2G([1,K1), U([1,K1),RH([1,K1))
    RQI = RH(I3, K3) * Q(I3, K3)
    ERG=(RGT-R33D)/RG3U
    IF(IT.GE.10)ERT=.005
    IF (ABS (ERW) . LT . EHT) GO 10 20
    CALL ERROR(5, IT, DNU3, ERG, 1.1, DNUZ1, ERGZ1)
    GO TO 12
 20 XMU(13,K3)=ASIN(1./EM(13,K3))
    IF(B.GT.).) RETURN
    A=.5
    B≃.5
    GU TU 10
    END
```

```
SUBROUTINE PM(DNU, P2, T2, H2, EM2, G2, U2, RH2, PI, TI, HI, EMI, G1, UI, RHI)
  COWMON/S/ BHI1
  DTH=1./57.5
   IFAN=ABS(ONU)/DTH+1
  DUM=D.VU
   IF (IFAN.GT.1) DUM=DNU/FLGAT (IFAN-1)
  P1=P1
   T1=TI
  EM1=EMI
  H1≃HI
  G1 = G I
  RH1=RHI
  A1=SGRT(G1*P1/RH1)
  U1=UI
  Ui=U1*U1
  HT=H1+U1/2.
  P1=ALOG(P1)
  XNU=0.
  XNU1=0.
  IF (IFAN .NE . 1) IFAN=IFAN-1
  DO 10 I=1, IFAN
  XMU1=ASIN(1./EMI)
  B1=G1*EM1/CUS(XMU1)
  P2==B1*DUM+P1
  RH2=(P2-P1)/G1
  RH2=RH1*EXP(RH2)
  P2P=EXP(P2)
  PIP=EXP(P1)
  U2=U1=2.*G1/(G1=1.)*(P2P/RH2-P1P/KH1)
  H2=HI-U2/2.
  T2=FT(P2P,PHI1,H2)
  G2=FGAM(T2,P2P,PHI1)
   A2=G2*P2P/RH2
  EM2=SQRT(U2/A2)
  XNU=XNU1+DJM
  XNU1=XNU
  P1=P2
  11=12
  G1=G2
  EM1=EM2
  J1=U2
   RH1=RH2
TO CONTINUE
  P2=EXP(P2)
   U2=SQRT(U2)
  RETURN
  END
   END
```

```
SUBROUTINE PHI(IX,KX)
    COMMON/IN/PI,TI,NI,THI,FMI,GI,ZI,HI,RHI,UI
   COMMON/X/X(2,50),Y(2,50),Z(2,50),Th(2,50),XNU(2,50),
   1P(2,50),T(2,50),E4(2,50),XMU(2,50),Q(2,50),H(2,50),Rn(2,50),
   26(2,50)
    COMMON/P/PINE, PIUT, TTOT
    COMMUNICAICHI
    DNU=XNU(IX,KX)
    G=GI
    EM1=EMI
    GG=SuRT((G+1.)/(G-1.))
    XM1=SGRT(EM1**2=1.)
    XNU1=GG*ATAN(XM1/GG)-ATAM(XM1)
    EM2=DMU/(1.5-x 4U1)*(6.-EM1)+EM1
    TT3=1
910 XM2=SQRT(E42**2-1.)
    DNUT=GG*(ATAN(XM2/GG)-ATAN(XM1/GG))+ATAN(XM1)-ATAN(XM2)
    ERNU=DNU-DVUT
    IF (ABS (ERNJ) . LT. 1 . E = 04) GO TO 20
    CALL ERROR(6, IT3, EM2, ERNU, 1.11, EM21, ERNU1)
    GO 10 10
20 CONTINUE
    CALL EM30(EM2, EMX, X(IX, KX), G, Z (IX, KX), ZI)
1313
    P(IX,KX)=PTOT/(1.+(G-1.)/2.*EMX**2)**(G/(G-1.))
    T(IX, KX)=TTJT/(1.+(G-1.)/2.*ENX**2)
    EM(IX,KX)=ENX
    XMU(IX,KX)=ASIT(I.ZENX)
    AX=SQRT(G*RGAS*I(IX,KX))
    Q(IX,KX)=E VX*AX
    RETURN
    END.
```

	SUBROUTINE GNURE(RH,Q,P,T,R, X,X1,CF,ST,L) COMMON/CP/CPI, RGAS	
	COMMON/O/PHII COMMON/HOT/AH(3), BH(3), CH(3), XSTR, REC, RT, SH, IT, IVIS HDEL=R-0*0/2.	
	HAW=1.+REC*Q*9/2./HDEL IF(IT .EQ.0)TV=AH(L)*(X-X1)**2+BH(L)*(X-X1)+CH(L)	_[]
	IF(IT .EQ.1)GO TO 46 HW=FH(P,PH[1,TN)	1)
pps <del>Tra B</del>	HW=HW/HDEL GO TO 48	· i
48	пи=HAN A=HAN-1.	<u> </u>
	B=HW=1. C=SQRI((A+B)**2+4.*A)	
	FC=A/(ASIN((A-B)/C)+ASIN((A+B)/C))**2 FRX=HAN**(.772)/(FC*(HN)**(1.474))	_: -
	CALL VIS(T,XMMJ) REX=RH*J*(X+XSTR)*RT /XMMU	. ,
	REXI=FRX*REX CFI=.088*(ALUG10(REXI)-2.3686)/(ALUG10(REXI)-1.5)**3	<u>_</u> ;
	CF=CFI/FC ST=CF*SH/2.	
	RETURN END	<u> </u>
	SUBROUTINE VIS(1,XMHU) XMUU=2.27****1.5*1.6-08/(1+198.6)	
	RETURN END	
·	END	
		<del> </del> -
<b></b>		<u> </u>
		~~~ <b>~</b> [``
		L.:
		1
		•

```
SUBROUTINE SMARF(x1, Y1, Z1, x2, Y2, Z2, x3, Y3, Z3, X4, Y4, Z4, AVX, AVY, AVZ,
       IXNX,XNY,XJZ,AS,XO,YO,ZO,L#)
       DIMENSION XPA(4), YPA(4), ZPA(4), XI(4), ETA(4)
       XPA(1)=x1
       YPA(1)=Y1
        ZPA(1)=Z1
        ZPA(2)=22
        YPA(2)=Y2
       XPA(2)=X2
        XPA(3)=x3
        YPA(3)=Y3
        ZPA(3)=Z3
ZPA(4)=Z4
        YPA(4)=Y4
        \overline{XPA}(4) = \overline{X4}
        T1x=x3-x1
        71Y=Y5-Y1
        T1Z=Z3-Z1
T
        T2X=X4-X2
        T2Y=Y4-Y2
        12Z=Z4-Z2
XNX=T2Y*T1Z=T1Y*T2Z
        XNY=11x + 12Z - 12x + 11Z
        XNZ=T2x*11Y-11x*T2Y
        VN=SURT(xnx**2+xny**2+xnZ**2)
        IF(VN.LE.1.E=13)GO TO 6
        XVX=XVX\V
        XNY=XNY/VN
        XNZ=XNZZVN
        D=XNX*(AVX-X1)+XNY*(AVY-Y1)+XNZ*(AVZ-Z1)
        PD=ABS(D)
        T=SQRT(F1X*T1X+T1Y*T1Y+T1Z*T1Z)
        11x=11x/1
        T1Y=T1Y/[
        TIZ=TIZ/T
        T2X=XNY*T1Z=XNZ*T1Y
        TZY=XNZ*T1X-XNX*T1Z
        T2Z=XNX*T1Y+XNY*T1X
        DU 1000 J=1,4
        TPA(J)=YPA(J)+XNY*D
        ZPA(J) = ZPA(J) + XNZ * D
        D==D
        XDIF=XPA(J)=AVX
        YDIF=YPA(J)-AVY
        ZDIF=ZPA(J)-AvZ
        XI(J)=T1X*xD1F+T1Y*YD1F+T1Z*ZD1F
   1000 ETA(J)=T2X*XDIF+T2Y*YDIF+T2Z*ZDIF
        XIO=(XI(4)*(ETA(1)-ETA(2))+XI(2)*(ETA(4)-ETA(1)))/(ETA(2)-ETA(4))
       1/3.
        ETAU=-ETA(1)/3.
        DO 1020 J=1,4
        TIX-(L)IX=(L)IX
   1020 ETA(J)#ETA(J)#ETAD
        XD=AVX+T[X*X]D+T2X*ETAO
        YU=AVY+T1Y*XIO+T2Y*ETAU
        ZO=AVZ+T1Z*XIO+12Z*ETAU
        AS=(ETA(2)-ETA(4))*(XI(3)-XI(1))/2.
        AS=ABS(AS)
        RETURN
      6 CONTINUE
        ZVA=OZ & YVA=CY & XVA=UX
```

```
RETURN
END
SUBROUTINE THM(X1, Y1, Z1, X2, Y2, Z2, X3, Y3, Z3, X4, Y4, Z4, P1, P2, P3, P4,
101,02,03,04.Ti,12,T3,14,TH1,TH2,TH3,TH4,XK1,XK2,XK3,XK4,AVG,
2XXTHX, XYLFT, XX MUM, CFF, ST, LH)
COMMON/O/FHI1
 COMMON/P/PINF, PTOT, TTOT
COMMUNICP/CPI,
COMMON/SHF/XSHFT, YSHFT
 COMMON/HOT/AH(3),BH(3),CH(3),XSTR, REC,
                                                    RT, SH, IT, IVIS
 COMMON/VISF/XVTHX, YVLFI, XVMUM
 P=XK1*P1+XK2*P2+XK3*P3+XK4*P4
 Q=XK1*Q1+X<2*Q2+XK3*Q3+XK4*Q4
 T=xK1*T1+xK2*T2+xK3*T3+XK4*T4
 TH=XK1*TH1+XK2*TH2+XK3*TH3+XK4*TH4
 H=FH(P,PHI1,T)
 RH=RHEQ(H,P,PHI1,DUM)
 R=H+Q*Q/2.
 R=CPI*T+U*3/2.
 AVX=XK1+X1+XK2+X2+XK3+X3+XK4+X4
 AVY=XK1*Y1+xK2*Y2+xK3*Y3+XK4*Y4
 AVZ=XK1+Z1+XK2+Z2+XK3+Z3+XK4+Z4
 CALL SNARF (X1, Y1, Z1, X2, Y2, Z2, X3, Y3, Z3, X4, Y4, Z4, AVX, AVY, AVZ, XNX,
1XNY, XNZ, ASS, XO, YO, 7(1, LH)
 CFF=0.
 XBP=0.
                                                XO, XBP, CFF, ST, 1 )
 IF(IVIS, EQ. 1) CALL GNURE (RH, Q, F, 1, R,
 RHQ=RH+0+0/2.
 PAV=P-PINF
 DXTHX==PAV *X"X * ASS
 DYLFT= PAV*XNY*ASS
 XNZZ=1.
 IF (LH.EN.3) XNZZ=XNZ
                         *COS(TH) *ASS*RHQ
 DXTHXV=-CFF
                  *SIN(TH)*ASS*RHQ
 DYLFTV=CFF
 DXTHXV=DXTHXV*AVG
 DYLFIV=DYLFIV * AVG
 XMS=XU-XSHFT
 YMS=YU-YSHFI
 DMUMY=YMS*DXTHXV+XMS*DYLFTV
 XVTHX=XVTHX+DXTHXV
 YVLFT=YVLFT+DYLFTV
 \nabla \nabla M \Box M = X \nabla A \Box M + D M \Box M \nabla X
 DXTHX=DXTHX*AVG+DXTHXV
 DYLFT=DYLFT*AVG+DYLFTV
 DMOM=YMS*DXTHX+XMS*UYLFT
 XXTHX=XXTHX+DXTHX
 XYLFT=XYLFT+DYLFT
 MCMO+MOMXX=MOMXX
 RETURN
 END
```

<sup>Sl</sup> Mo≂u.

```
SUBROUTINE CNT
   COMMON/IN/PI,TI, SI, THI, ENI, GI, ZI, NI, RHI, UL
   CUMMUNICATE/TIC, PIU, AC, GC, PC, THC, XNUC, ZC, EMC
   COMMUNIPIPINE, PIDI, FICT
   COMMUNICAICHI.
   COMMDN/X/X(2,50),Y(2,50),Z(2,50),TH(2,50),XMU(2,50),
  1P(2,50),T(2,50),EV(2,50),XMU(2,50),Q(2,50),H(2,50),RH(2,50),
  2G(2,50)
   A=1. 5 B=0.
                             GIS=GI $ZIS=ZI$EMIS=EMI
   111=1
   RB = XNU(1,2) + IH(1,2)
   TH(2,1) = TH(1,1)
型0 SLA=A*TAM(TH(2,1))+B*TAM(TH(1,1))
   SLB=TH(1,2)-x40(1,2)
   SLB=A*TAN(SLB)
   IF(B.GT.O.)SLB=SL3+B*TAN(TH(2,1)-XMU(2,1))
   CALL GEM(x(1,2),y(1,2),SLB,x(1,1),y(1,1),SLA,x(2,1),y(2,1))
   Z(2,1)=GEIZ(X(2,1))
   XNU(2,1)=RB=TH(2,1)
   DNU=XNU(2,1)-XNU(1,1)
   CALL PM(DNU ,P(2,1),T(2,1),H(2,1),EM(2,1),G(2,1),Q(2,1),RH(2,1),
  IP(1,1),T(1,1),H(1,1),EN(1,1),G(1,1),G(1,1),RH(1,1))
   RQ3D=RH(2,1)*Q(2,1)/Z(2,1)
   DNU3=DNU
   ERT=.001
   ITEI
10 CONTINUE
   CALL PM(DNJ3,P(2,1),T(2,1),H(2,1),EM(2,1),G(2,1),Q(2,1),RH(2,1),
  1P(1,1),T(1,1),H(1,1),EM(1,1),G(1,1),Q(1,1),RH(1,1))
   RUT=RH(2,1)*0(2,1)
   ERG=(RGT-RG3D)/RG3D
   IF (11.GE.10) ERT=.005
   IF (ABS(ERG).LT.ERT)GO TO 14
   CALL ERRUR (7, IT, ONU3, ERG, 1.1, DNUZ1, ERGZ1)
   GO TO 10
4 XMU(2,1)=ASIN(1./EM(2,1))
    TTOT=TTC & PTOT=PTC & GI=GC &ZI=ZC &EMI=EMC
   RCHXNUCHTHO
    TH(2,2)=TH(2,1)
   XNU(2,2)=RC+TH(2,2)
    X(2,2)=x(2,1)
   A(5:5)=A(5'1)
    Z(2,2)=GETZ(x(2,2))
    CALL PMI(2,2)
   ER3=(P(2,1)=P(2,2))/PC
   IF (ABS(ER3). LT. 1. E-04) GO TO 16
    CALL ERROR(B , ITT, TH(2,1), ER3,1.01, TH23, ER23)
                             GI=GIS SZI=ZIS SEMI=EMIS
    GU TO 20
TE CONTINUE
                             GI=GIS $ZI=ZIS $EMI=EMIS
    IF (B.GT.O.) RETURN
    ITT=1
    A=.5 & B=.5
    GO 10 20
    END
```

```
SUBRUUTINE CONL (DNUE)
  COMMON/X/X(2,50), Y(2,50), Z(2,50), TH(2,50), \times \text{MU}(2,50),
  1P(2,50),1(2,50),£M(2,50),XMU(2,50),0(2,50),H(2,50),RM(2,50),
 26(2,50)
  COMMON/CHL/XCS,YCS
  COMMON/P/PINF, PTOT, TIOT
  COMMON/F/PF, IF, AF, THF, EMF, GF
  COMMON/CP/CPI,
                       RGAS
  COMMUNICATE/FIC.PIC.WC.GC.PC.THC.XNUC.ZC.EMC
  PCC=(PF+P(1,1))/2.
  GM1=GF-1.
  GP1=GF+1.
  EMF2=EMF *EMF
  DUM=1.+GM1*EMF2/2.
  PTF=PF * DUM * * (GF/GM1)
  TTF=TF*DUM
  GIS≃GI
  XMUF=ASIN(1./EMF)
  IT=1
  BET=(THF-XMUF+TH(1,1))*1.1-THF
20 DUM=(EMF*SIN(BET))**2
  PC=(2.*GF*)UM=G41)/GP1
   TC=PC * (G41 * DUM+2.)/DUM/GP1
  EMC=(EMF2*(GP1*PC+GM1)=2.*(PC*PC=1.))/(GM1*PC+GP1)/PC
  EMC=SWRT(E VC)
  PC=PC*PF
  THC=TAN(BET) * (GP1 * EMF2/(DUM-1.)/2.-1.)
   THC=ATAN(1./THC)+THF
  PTC=(2.*TC/(G41*EMF2+2.))**(GF/G41)
  PTC=PC/PTC
  TIC=ITF
   TC=TC*TF
  RA=XNU(1,1)+TH(1,1)
   X(2,1)=XC2 SY(2,1)=YC2 STH(2,1)=THC
   Z(2,1) = GETZ(xC2)
   XNU(2,1)=RA-TH(2,1)
  DNU=X4U(2,1)-X4U(1,1)
   CALL PM(DNU ,P(2,1),T(2,1),H(2,1),EM(2,1),G(2,1),Q(2,1),RH(2,1),
  IP(1,1), T(1,1), H(1,1), EM(1,1), G(1,1), U(1,1), RH(1,1))
   ER4=(PC+P(2,1))/PCC
   IF(ABS(ER4).LT.1.E-03)GO TO 16
   CALL ERROR (9, IT, BET, ER4, 1.05, BET1, ER41)
   CO 10 20
16 DNUE=XNU(2,1) -XNU(1,1)
   GI=GIS
   wC= NF
   GC≔GF
   ZC=Z(2,1)
   XNUC=0.
   RETURN
   END
```

 $z^{i-1}$ 

```
FUNCTION FH(P1,F,I1)
    P=P1*1.01325E+05/2116.
    T=117...8
    F2=F*F
    IF(F.LT.O.) GU TO 400
    IF (T.GT.2000.) GO TO 190
    IF(F.GT.1.) GO TO 191
120 A=1.E=07*(=.1042*F2 +.8242*F+.987)
   B=.001*(.01167*F2 +.1503*F+.938)
    C==.0284*F2 +.6731*F+.4293
    GO TÚ 290
B=.001*(-.1867*F2 -5.48*F+5.4)
    B=.001*(-.1867*F2 +1.11*F+.176)
    C==.0933*F2 +3.975*F=2.808
    GO TU 290
0 IF(F.GT.1.) GO TO 192
    A=.000001*(1.792*F2 +.3983*F+.31)
    B = .001 \times (-9.05 \times F2 - .07917 \times F + .245)
    C=10.86*F2 -.1183*F+.97
    GO TO 290
192 A=.000001*(4.81*F2 -13.9*F+11.59)
    B=.001*(-23.08*F2 +66.82*F-52.61)
    C=27.05*F2 =73.73*F+58.39
290 H1=A*T*T+6*T+C
    IF (T.LE.2000.) GO TO 370
    A10=ALOG(P)/2.3-5.
    Z9=.125*A10*A10
                                -.275*A10
    H1=H1*(1.+(1.+F)*(T/2000.=1.)*Z9)
FO H1=H1*1.E+06
    GO TO 340
400 T2=T*T
    T3=T2*T
    T4=T3*T
    75=14*T
    H1=A1*T+A2*T2/2.+A3*T3/3.+A4*T4/4.+A5*T5+A6
    H1=H1 *8314,/XMM1
ET CONTINUE
    FH=H1*10.7639
    RETURN
    END
```

```
FUNCTION FI(P1,F,H5)
    DATA 163/0/
    ITLau-U
    P=P1*1.01325E+05/2116.
    H=H5
             /10.7639/1.E+06
    F2=F*F
    A10=ALOG(P)/2.3-5.
    Z9=.125*A10*A10
                                -.275*A10
    IT=1
    IF(163,EQ.1) GO TO 1000
    I63=1
    T=1500.
    T0=1500.
    IF(F.GE.O.) GU TO 120
    T=600.
    T0 = T
000 CONTINUE
    IF(F.LT.O.) GO TO 400
    GO TO 120
 50 E0=(H-H1)/H
    IF(ABS(EU).LT.1.E-04) GO TO 340
500 T =T0*1.1
502 II=2
    IF(F.LT.O.) GO TO 400
    GU TO 120
100 E1=(H-H1)/H
    IF(ABS(E1).LT.1.E-04) GO TO 340
    IT=IT+1
    IF(IT.LT.21) GO TO 10
    IF(ABS(T-2000.).LT.10.) GO TO 830
    WRITE(6,831) P1,H5,T
131 FURMAT(* ERRUR IN FT*/* P1 = *E13.5,5X,*H1 = *E13.5,5X,*T = <u>*E13.5</u>
   1)
    STOP
130 IF (IFLAG, Ey, 1) GU TO 504
    IF! AG=1
    TO=2000.
    T=2000.
    IF(F.LT.O.) GO TO 400
    GU TO 120
 04 WRITE(6,11) E1
                                                        ERROR = \starE13.5)
 11 FORMAT(* TEMPERATURE IN FT SET TO 2000
    GU TO 340
 10 T9=T0-E0*(T-T0)/(E1-E0)
 05 E0=E1
    T0 = T
    T=19
    IF(F.LT.O.) GO TO 400
 20 A=1,E=07*(-.1042*F2 +.8242*F+.987)
    B=.001*(.01167*F2 +.1503*F+.938)
    C=-.0284*F2 +.6/31*F+.4293
    IF(F.LE.1.) GO TO 190
    A=1.E-07*(1.787*F2 -5.48*F+5.4)
    B = .001 * (-.1807 * F2 + 1.11 * F + .176)
    C=-.0933*F2 +3.975*F-2.808
 '0 IF(T.LE.2000.) GD TD 290
    A=.000001*(1.792*F2 +.3983*F+.31)
    B=.001*(-9.05*F2 -.07917*F+.245)
    C=10.86*F2 -.1183*F+.97
    IF(F.LE.1.) GU TU 290
    A=.000001*(4.81*F2 -13.9*F+11.59)
    H=.001*(-23.08*F2 +66.82*F-52.61)
```

```
IF (T.LE.2000.) GO TO 370
   H1=H1*(1.+(1.+F)*(7/2000.-1.)*Z9)
70 CONTINUE
   GO TO 350
400 12=1*1
   T3=T2*T
   T4=T3*T
   T5=T4*T
   IF(F.LT.-1.5) GO TO 450
   XMM1=16.043
   A1=4.249/67B
   A2==6.9126562E=03
   A3=3.1602134E-05
   A4==2.9715432E=08
   A5=9.5103530E-12
   A6==1.0186632E+04
   GO TO 460
C 23
450 CONTINUE
   A1=1.1202436
   A2=1.3905716E=02
   A3=2.0508374E=06
   A4=-1.1560272E-08
   A5=5.2386929E-12
   A6=5.3328896E+03
   XMM1=28.054
H1=H1*8314./XMM1/1.E+06
350 IF(IT.Eu.1) GO TO 50
   GD TO 100
   T0=T
    F1=1*1.8
    RETURN
    END
```

```
FUNCTION RHEQ(H,P1,F,T)
     T1=FT(P1,F,H)
     T=T1/1.8
     P=P1*1.01325E+05/2116.
     IF (F.LT.O.) GU TO 2260
     FNM=1.53*F*F=5.895*F+28.965
     FNN=1.6*F*F=10.6*F+33.6
     IF(T.GT.2000.) GO TO 2030
     XM=FNM
     IF(F.LT.1.) GO TO 2160
     XM=FNN
     GO TO 2160
2030 FF=F*F
     A==2.3*FF+4.01*F+1.736
     B=8.61*FF-15.42*F-6.66
     C==16.88*FF+33.21*F+14.58
     XN==.4375*FF+.0625*F+2.08
     D=A*(ALDG(P)/2.3)**1.5+b*(ALDG(P)/2.3)+C
     XM=FNM-D*((T-2000.)/1000.)**XN
     IF(F.LT.1.) GO TO 2160
     A==.822*FF+2.363*F+1.905
     B=2.76*FF=7.50*F=8.68
     C==3.6*FF+7.36*F+27.15
                                                                 Ļ
     XN==_47*FF+1.825*F+.35
     D=A*(ALUG(P)/2.5)**1.5+B*(ALUG(P)/2.3)+C
     XM=FUN=D*((T=2000.)/1000.)**XN
     GO TO 2160
2260 KF=F-.5
     IF(KF, EQ. -1) XM=16.043
     IF(KF.EQ.-2)x4=28.054
2160 RHEQ=P*X4/T/8314.3*6.2428E-02/32.174
     T=1*1.8
     RETURN
     END
```

FUNCTION FGAM(T1,P1,F) T=T1/1.8 T2=1\*T P=P1\*1.01325E+05/2116. XM=0. IF(F.LT.0.) GO TO 550 IF (T.LE.1000.) GO TO 440 XM==2.15E=08\*T2 +.000091\*T=.0695 #40 X4=4.E-09\*12 -.00002\*1-.019 IF(F.LE.1.) GO TO 470 XN=.0339\*SQRT(1)-.000391\*T-.681 470 G=-1.833E-07\*T2 +.00<u>0075\*T+1.367</u> IF(T.LT.500.) GU TU 520 G=2.E-08\*T2 -.000138\*T+1.423 IF(T.LT.2000.) GO TO 520 G=7.267E=08\*T2 =.000457\*T+1.85 G=7.26/E=05\*12 =.00043/X:T1.03 20 G=G+XM\*(ALJG(P)/2.3-5.)+XN\*(F=1.) GO 10 530 450 I3=12\*I T4=T3\*T CP=A1+A2\*T+A3\*T2+A4\*T3+A5\*T4 G≂CP\*(CP=1.) 30 CONTINUE FGAM=G RETURN END H

# 24 <u>3</u>	3970.2 488.8	<u>i.</u>	0.	2,776	21,443			
52.90	488.8 1.	18.965 18.54	0. 0. 1.11	2,776 8,636 0.	1.4 3.12	7,866	<b>6</b> .	
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